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Yield and foliar composition of corn as affected by fertilizer rates and environmental factors

Regis Dale Voss
Iowa State University

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YIELD AND FOLIAR COMPOSITION OF CORN AS AFFECTED BY
FERTILIZER RATES AND ENVIRONMENTAL FACTORS

by

Regis Dale Voss

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Soil Fertility

Approved:

Signature was redacted for privacy.

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Ames, Iowa

1962

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I. INTRODUCTION

Emphasis has been placed on soil fertility research which involves the establishment of quantitative relationships between crop yields and multiple factors of production. Although numerous factors, both controlled and uncontrolled, affect crop production, the use of controlled variables such as plant nutrients from fertilizers has attracted the most attention.

It has been noted by many scientists that a particular crop may vary in its response to applied nutrients depending on season and location effects. This presents a problem in extrapolating predicted yields from one experimental location to a larger geographical general area and, therefore, recommendations also. The causes of this uncertainty have, in general, been recognized, but no attempt has been made to account for their effects on response of crops to applied nutrients.

This uncertainty concerning the influence of uncontrolled variables accentuates the need to conduct fertility research in a framework that will provide for the quantification of the effects of soil sources of plant nutrients, management factors, and weather on the response of crops to applied nutrients.

This study was undertaken to ascertain the effects of selected uncontrolled soil variables, management factors, and weather on the response of corn to applied N, P, and K in

multi-rate experiments. Also studied were the effects of these variables on plant composition as measured by N, P, and K percentages in the corn leaf. The development of methodology for attaining these goals is presented.

II. REVIEW OF LITERATURE

Corn has been shown to respond to mineral sources of N, P and K applied separately and in combination with each other. The degree of response to these elements has been shown to differ because of initial levels of soil nutrients, weather factors and certain management factors. References which appear to be most relevant to response of corn to N, P and K as fertilizers measured by grain yield and plant composition and the degree of response are noted in this review.

A. Factors Affecting Corn Yields

1. Applied fertilizers

That corn should respond to some degree from application of N, P and K salts depending on the amounts of these elements supplied by the soil has been variously reported. Most of the beginning work involved a single variable with a basic, uniform application of the other nutrients. These first years of experimentation indicated that more information was needed on the effects of higher rates and combinations of N, P and K fertilizers. Experiments were started in Iowa in 1947 using broadcast N, P and K in factorial combinations with hill or row fertilizer comparisons on the split plots.

The first efforts of the Iowa research involving NPK factorial experiments were presented by Dumenil and Nelson

(1948). Their results indicated that 62 of 164 NPK factorial experiments with corn, oats and legume hays had significant interactions between fertilizer elements, both positive and negative. They concluded that the use of factorial designs wherein the different fertilizer elements and rates are used in all possible combinations appears desirable as the experimenter will not make erroneous conclusions wherever interaction between fertilizer elements occurs.

A significant contribution to the knowledge of quantification of corn yields as a continuous function of two fertilizer variables was made by Heady et al. (1955). The experiments upon which this study was based were designed to allow (1) estimation of the crop production surface generated by fertilizer variables and (2) specification of economic optima in levels of fertilization and combination of nutrients. The corn experiment, on calcareous Ida silt loam soil, included nine rates of N and P. A square root transformation of the full term quadratic function in two variables that included an interaction term for N and P was the best fitting function for these data. The function was used to derive yield-nutrient and nutrient-nutrient relationships besides relevant economic relationships. The importance of this research lies in the application of marginal economic analysis to more than one input variable and therefore emphasizes the need for yield data obtained from more than one input variable.

Another study that was sequential to the above mentioned study was presented by Brown et al. (1956). This experimentation was designed to obtain basic yield-fertilizer relationships and to apply marginal economic analysis in order to predict optimum levels of fertilization and optimum ratios of nutrients with profit maximization as the criterion of selection. A 5x4x3 factorial for N, P, and K was the design used on two soil types and a 3x3x3 factorial on another soil type. A second degree polynomial equation was fitted to the data from each experiment and it is of interest that each had different significant terms. However, it was not the object of this study to ascertain the differences due to the three soil types.

Doll et al. (1958) presented similar results as the two previously mentioned studies. However, these authors also presented an analysis of response of corn when irrigated and response to residual fertilizer from the previous season.

Hutton et al. (1956) calculated rates of N, P, and K to give maximum yields from four years of data obtained from five levels of N, P, and K and two levels of dolomitic limestone applied to a Red Bay fine sandy loam in western Florida. Although they did not pool the data in order to quantify differences in response among years, they did note the amount of P required for maximum yield decreased as the experimentation progressed as did K. No response to N was obtained one year

when rainfall was limiting and a depression by N was obtained when early rainfall produced a lush growth and was followed by drought.

Although other studies involving singular nutrient studies may be mentioned, there is a paucity of literature concerning multi-rates with more than one variable. A review of the mineral nutrition of corn by Nelson (1956) obviates the need for repetitious review of such literature.

2. Applied fertilizer influenced by initial soil fertility

Correlation studies relating methods of measuring soil nutrients to response of field crops to additions of fertilizers are conducted by most state experiment stations. However, until recent years empirical functional relationships of crop yields on fertilizer variables have been determined with no allowance being made for available soil nutrients initially in the soil before experimentation. Spillman (1933), who conducted a series of N rate experiments over a period of six years, noted a progressive increase of nitrogen in the soil. On another series of experiments on a soil originally high in P, he noted a progressive decrease in soil P. By comparing the yield equations he concluded that the change of amounts of soil nutrients would invalidate these equations defining yield only as a function of added fertilizer.

Brown (1956) and Heady et al. (1955) found that one year's experimental data would not accurately describe the

next year's response because of residual fertility. Heady (1956) further concluded that quantitative differences due to residual fertilizer should be determined over time for response functions derived from fertilized fields.

Hutton et al. (1956) noted that corn responded less to the same amounts of fertilizer over succeeding years. Baird and Fitts (1957) found that in two proximate corn experiments depressed yields were observed at high rates of applied fertilizer in one while the other showed no effect at the same rates. These investigators attributed this to different amounts of nutrients initially in the soil and concluded that the initial soil fertility level would have to be evaluated in calculating optimum fertilizer rates. Anderson (1956) in recognizing the effect of available nutrients in the soil before fertilization outlined the importance in adjusting for available nutrients while considering errors involved in the procedure. He succeeded in theoretically quantifying the bias in applying a predictive yield equation derived from one level of available nutrients to that of another.

Heady and Pesek (1957) in a discussion of economic methodology for soils, differing in amounts of available nutrients, stated that unless the underlying family of relationships is known, soil tests cannot be used to find the origin of a specific yield surface with respect to others and

a new response function has to be developed for each soil with significantly different amounts of available nutrients initially present.

Several workers have pursued this line of reasoning in trying to evaluate the differences in yield functions by scaling the initial fertility level, i.e., putting the amounts of initial soil nutrients in the same units as added fertilizer. Among these workers are Anderson (1956), Hurst and Mason (1957), Jensen (1957), Jensen and Pesek (1959), Voss (1960) and Voss and Pesek (1962). These workers examined whether second-degree yield surfaces could be considered as translated portions of the same general second-degree surface over the total nutrient plane. A certain degree of success was attained, but Voss and Pesek (1962) obtained evidence from a wide range of initial soil nutrients that discounted the hypothesis in its simplest form. In this situation soil P apparently was the yield limiting factor and by arbitrarily dividing thirty soils into three groups on the basis of P fertility the existence of different aggregate surfaces of restricted generality was accepted. Voss and Pesek (1962) obtained a generalized equation by not attempting to scale the initial soil nutrients but used the application of least squares to the soil test values, fertilizer inputs and observed yields. Dumenil (1958) used this method for a generalized yield function for corn involving N and P ferti-

lizers in a large number of fertilizer experiments in different years and on many soil types.

Hanway and Dumenil (1955) developed an equation which predicted yield response as a function of applied N and soil nitrification rate for Iowa soils. This equation used for making nitrogen recommendations for corn in Iowa avoids scaling the soil test value for N in terms of the fertilizer source used.

Others who have followed a similar approach by incorporating soil test values per se in a yield function are Gomez (1960) and Besson (1961) for oats and mixed meadow, respectively. By avoiding the scaling problem these workers have been able to ascertain the effect of initial soil nutrients on yield with and without fertilizer.

The influence of soil nutrients on the effects of applied fertilizer on crop yield has not been answered conclusively, although considerable effort has been put forth for ascertaining these effects. It appears that a logical approach as employed by some workers is to include the soil nutrients in a second-degree yield equation and allow them to interact with the applied nutrients when this interaction occurs. It does not seem unreasonable to assume that the soil nutrients may substitute for applied nutrients or to complement them. Also the fact that a soil nutrient may be a limiting factor suppressing the effect of another applied

nutrient seems logical. These effects may be included in a second-degree equation as linear by linear or higher order terms.

3. Applied fertilizer influenced by stand, hybrid and climate

The preceding discussion has elucidated the effect of initial soil fertility on response to applied fertilizer and therefore this discussion will be restricted to other factors.

Viets and Domingo (1948) conducted experiments in Oregon for two years involving 15 corn hybrids grown at two N levels one year and 18 hybrids grown at three N levels the succeeding year with irrigation both years. Yield differences due to N levels among hybrids were highly significant the first year but not the succeeding year. However, a high coefficient of variation was obtained the second year, and the large error term prevented the ascertaining of a significant interaction.

A corn hybrid, stand level and N rate experiment conducted by Lang et al. (1956) resulted in all possible interactions contributing to yield. These workers noted the effect of season on these interactions. This work is of interest in that N was the yield limiting factor when population was varied. It would appear that a linear N by quadratic stand term would explain a portion of the variation in yield obtained.

Pesek et al. (1959) used the results from 2 corn hybrid and stand level experiment and from two corn hybrid, stand

level and N rate experiments conducted on different soil types to evaluate the affects of stand level on corn yields. These workers concluded that recommendations for stand and plant nutrients are not independent of each other. The data also indicated differences in response obtainable from two corn varieties subjected to similar growing conditions.

Terman (1960) summarized 174 P rate experiments in the southeast for many crops. When soil P increased, measurable differences due to applied P decreased and limiting yields were lower on low P sites. Limiting yields varied among sites and when the data were pooled, a fertilizer by location interaction was observed. No explanation could be made of this because inadequate measurements were available, but a deficiency of water for summer crops was thought to be the main limiting factor. Engelstad and Doll (1961) analyzed the effect of rainfall and temperature on the response of corn to applied P and found that rainfall in June and July had the greatest beneficial effect and maximum daily temperature had the most detrimental effect during June, July and August.

Carlson et al. (1959) conducted two years of research with corn to determine the effect of moisture level, applied N and plant density on yield. Neither N nor plant density influenced yields in the nonirrigated experiment but both had an effect in the irrigated experiment. Due to the high experimental error no valid conclusions could be drawn. However,

they failed to note apparent N by stand and moisture by N interactions. Also moisture was limiting response to N over stand levels.

Parks and Knetsch (1959) made a significant contribution in quantifying the effect of weather on the response of corn to applied N. They indexed drought conditions for three seasons and related corn yields to N level and drought index by multiple regression. The index, calculated by a soil moisture balance method, accounted for a decrease in yield and in the response to N. However, decreasing returns were not reached probably because stand was held to 12,000 plants per acre.

Fitts et al. (1959) reported that corn yields obtained from N, P and K experiments on Norfolk soils could be expressed as a function of organic matter, soil reaction, applied N and a drought index. These soils did not respond appreciably to P and K so these effects were not included in the function. Drought, as measured by the drought index which was obtained from mean yields of the experiments and a moisture balance method, reduced the response to N and reduced total yields.

4. Planting date, stand level and hybrid

Dungan (1944) reported that date of planting influenced corn yields. Early planting of late season varieties gave best yields in northern and central Illinois. In central

Illinois planting on May 21 reduced yield by 4.9 bushels per acre as compared to May 2 and a June 11 planting reduced yield by 23.3 bushels per acre compared to the May 2 date.

Miller et al. (1949) found that corn hybrids vary in yielding ability with stand density. These investigators also noted that higher stands were needed for maximum yields in humid areas and lower stands in drought areas.

Duncan (1954) conducted four experiments on different soil types and under different initial fertility conditions. He reported that yields were influenced by stand density, initial fertility level and to a lesser extent by the hybrids grown. The data indicated a marked fertility by stand interaction on three out of four experiments. He concluded that neither the soil fertility level nor the hybrid itself can be critically studied unless plant population pressure on soil fertility level is being exerted to a considerable degree.

In an excellent review of all factors connected with stand and yield Dungan et al. (1958) stated that greater corn grain production is obtained from higher stands on soils of high productivity, plants gain in grain-producing efficiency as stand density increases and hybrids differ in respect to production at different stand levels.

5. Climate

Many workers have attempted to characterize corn yields as functions of monthly precipitation totals and temperature

averages. Although the method of approach has differed among workers, comparable results have been obtained. One of the earliest workers, Smith (1914), concluded that rainfall was the major factor controlling corn yields and that July rainfall was the most important. That moisture deficits during the time of pollination are most detrimental to corn yields has been substantiated by Howe and Rhoades (1955) and Holt and Van Doren (1961). Robins and Domingo (1953) found that moisture deficits for one to two days during pollination reduced yield 22 percent and six- to eight-day deficits reduced yield 50 percent.

High maximum daily temperature was dominant over rainfall in having an adverse effect on corn yields according to Davis and Harrel (1942). Hendricks and Scholl (1943) found that high temperature was beneficial during periods of sufficient moisture and detrimental during periods of insufficient moisture. Bates (1955) used data from 1913 to 1953 in Texas to ascertain that monthly evaporation, temperature, and relative humidity were more closely correlated with yield than rainfall at any period of the year, and June variables had the highest correlation with yield.

Runge and Odell (1958) used orthogonal polynomials, according to the method of Hendricks and Scholl (1943), on data from 1903 to 1956 and found that yields were influenced beneficially by precipitation preceding anthesis and detri-

mentally by maximum temperature during anthesis. Thompson (1962) used a second-degree equation to evaluate the effect monthly totals of precipitation and averages of temperature for states had on yearly average state corn yields. June, July and August temperature and July rainfall had the most significant effects in Iowa.

All of the workers noted above have used long time data averaged over a substantial geographical area. Thornwaite (1936) pointed out that it is futile to correlate average county yields with monthly or annual precipitation records within that county but that a significant advance could be made in the statistical study of the relation between climate and crop yields when small areas such as a square mile can be related to the distribution of individual rains throughout the growing season. Workers such as Parks and Knetsch (1959) and Fitts et al. (1959) have used weather measurements at the experimental sites to evaluate its effect on the response of corn to applied fertilizer.

B. Factors Affecting Water Utilization by Corn

Linscott et al. (1962) found that N fertilized corn produced deeper and more extensive root systems than unfertilized corn during the early part of the season. Although water use in fertilized plots was greater, good N nutrition resulted in increased root production and increased

moisture utilization during the critical period of plant development prior to and during tasseling and higher yields resulted.

Depth of rooting has been shown to affect water usage. Holt and Van Doren (1961) and Russell and Danielson (1956) measured utilization in the upper 5 feet of the soil profile. Reimann et al. (1945) noted that corn plants remained turgid and continued to grow when no available moisture was present from the surface to a depth of $3\frac{1}{2}$ feet. The pattern of moisture removal is from the surface downward according to Russell et al. (1940). By using tensiometers it was shown that corn roots first absorbed moisture at a shallow depth immediately beneath the plant. Absorption of moisture then extended laterally until most of the available moisture at that depth was depleted. After that, absorption of water occurred at successively greater depths. These observations were made on two major corn soils in north central Iowa.

It would be expected that as soil moisture tension and moisture content varied, the water use by the plant as transpiration and evaporation loss from the soil surface would also vary. Peters and Russell (1959) concluded from an experiment, which entailed plastic covered and uncovered plots with rainfall and irrigation treatments, that 50 percent of total evapotranspiration could be accounted for by evaporation from the soil surface. They made no adjustment for change in

microclimate and further concluded that transpiration was influenced in a minor way by plant population and soil moisture environment. However, Peters (1960) reported that when plants were subjected to a high evaporation demand, growth was found to be profoundly influenced by both soil moisture tension and moisture content.

Aubertin and Peters (1961) found that individual plants in a high plant density situation would wilt sooner than those in a low plant density environment. This was attributed to a higher energy absorbed under high stand density and therefore more transpiration.

The stage of development of the corn plant was found by Fritschen and Shaw (1961) to influence evapotranspiration. These researchers further stated that open pan evaporation may be used to estimate evapotranspiration provided a relationship between crop and open pan evaporation be established for a given area.

The research in this area may be summarized as follows. Monthly measures of weather factors appear to be satisfactory for long time data or average data over a broad geographical area. In order to elucidate the effects of weather on a particular experimental site specific weather measurements are needed at that site, the effect of the soil must be characterized and the crop grown should be considered. The latter approach integrates the effect of soil-plant-climate on water

use. Shaw (1961) devised a method for estimating soil moisture depletion under corn by considering the soil, plant and limited meteorological data. The method which is used to estimate moisture depletion in this dissertation is described in the following paragraphs.

Shaw (1961) used only open pan evaporation data, which provides an integrated value of the meteorological factors causing evapotranspiration to estimate evapotranspiration. This method compares favorably with the method of Penman (1948) and requires less time and data to compute. He divided the season into 3 periods as follows: April to June, June to August and August to November. His estimates of soil moisture depletion were compared with actual soil moisture measurements taken at the end of each period.

Computation of the soil moisture balance for April to June considered the following items: field capacity for each one foot layer of soil to 5 feet, moisture content of profile on starting date, 0.1 inch evaporation lost per day when water available in surface 6 inches (a bare surface is assumed during this period) and daily precipitation gain after adjusting for runoff as affected by antecedent precipitation and precipitation amount. A correlation of 0.96 was obtained between actual and predicted soil moisture found in June.

Computation of the soil moisture balance for June to August considered the following items: field capacity for

each layer of soil to 5 feet, moisture content of profile on starting date, loss due to evapotranspiration as determined by multiplying weekly pan evaporation daily average value by a crop development factor and adjusted for available water in root zone and atmosphere demand, and daily precipitation gain adjusted for runoff as in first period. A correlation of 0.96 was obtained between actual and predicted soil moisture present in August.

Computation of the soil moisture balance for August to November considered the following items: field capacity of the upper 5 feet of soil, moisture content of profile on starting date, loss due to evapotranspiration as determined by multiplying weekly pan evaporation daily average value by a crop development factor before October 1 and by 0.35 after October 1 and adjusted for available water in root zone and atmosphere demand. Water loss after October 1 determined by pan evaporation and crop development factor only, and daily precipitation gain adjusted for runoff as in previous periods. A correlation of 0.96 was obtained between actual and predicted soil moisture present in November.

C. Factors Affecting Nutrient Concentrations in the Plant

1. Soil and fertilizer sources of nutrients

Dumenil (1958) has presented an exhausting review on this subject and therefore only recent and limited previous work

involving corn will be cited.

Spies (1956) found that applied N increased leaf N concentration, whereas applied P did not affect it and applied K decreased it at high levels of soil K. Tyner and Webb (1946) reported that K applied at 80 pounds per acre had a slight depressive effect on leaf N but that P had no effect. Kranz and Chandler (1951) noted that N fertilizer not only consistently increased the N percentages but also increased the P and K percentages of the leaves, particularly on soils high in these nutrients. Also P and K fertilizers had little effect on the N percentages.

In four N-stand level-hybrid experiments Holmes (1956) found that leaf N content generally increased with N application. However, one experiment showed no change in leaf N even at a 200 pound N application. No explanation was given except that soil N was at a high level. He also found that in three of his experiments a decreasing increase of leaf N occurred with high additions of fertilizer N.

Dumenil (1958) summarized the effect of N fertilizer on P content of leaves as having shown considerable variability. Generally, N fertilizer has increased the leaf P when N availability was low and P availability medium to high. Hanway (1962) reported that a severe N deficiency resulted in low P and high K in the leaves. However, Tyner and Webb (1946) reported no effect of N and K on leaf P content. But,

Spies (1956) found that N and P fertilizer increased leaf P concentration. As an explanation for the increase in P concentration from N fertilization Bennett et al. (1953) pointed out that the more extensive root system from N fertilization of a low-N soil may increase P uptake. Since N and P are closely associated in proteins and enzymes, the increased N uptake and utilization in organic materials may increase the utilization of P and increase the uptake gradient for P.

Fewer reports are concerned about the uptake of K although there has been recent emphasis on this subject. Tyner and Webb (1946) found that N fertilizer applied as ammonium sulfate depressed leaf K percentage and that a reduction in N utilization accompanied a K depression. They also noted that P had no effect on K content in the leaf. Spies (1956) found that soils high in exchangeable K obliterated any effect that N, P or K fertilizer may have on leaf K. However, Holmes (1956) reported that increased N levels decreased the leaf K percentage in experiments in central Iowa in 1953. Hanway et al. (1962) summarized 41 K fertilizer corn experiments conducted in the north central region of the United States. These workers found that uptake of K fertilizer was inversely related to the level of exchangeable K in the soil and to the percent K in corn leaves from plots that received no fertilizer K. Exchangeable K in the subsoil improved the correlation between K contents of the corn plants and

exchangeable soil K in the plow layer.

2. Climate, stand and other factors

Under severe drought conditions, Ellis et al. (1956) found limited increases in N and P content of corn leaves from N and P fertilizers although leaf levels were low. On the K-deficient soils, the K fertilizer increased leaf K markedly and increased yields to a lesser degree. Mederski and Wilson (1960) noted that an increasing level of soil moisture increased both total and percentage of P, K and Mg in corn plants. They observed that the level of atmospheric humidity appears to interact with the effect of soil moisture on ion absorption.

On the basis of a comparison of irrigated and non-irrigated corn with a manure plus ammonium nitrate application, Jenne et al. (1958) reported that N percent was approximately the same but P percent decreased and K percent increased on the non-irrigated site. Hanway et al. (1962) noted that corn plants contained adequate K under drought conditions and that the number of plants per acre did not influence leaf K percent.

Jordan et al. (1950) reported that higher plant populations increased total P uptake. Holmes (1956) found that stand significantly decreased N content at all four sites and P content at two sites. In two of the experiments, significant, positive N by stand interactions on leaf N and P were present. Stand had a depressing effect on both leaf N and P

at low levels (0 and 100 pounds per acre) of applied N but very little at the high level of 200 pounds per acre. He also reported that highly significant differences in leaf N, P and K occurred among hybrids. His data suggested a hybrid by season interaction on nutrient uptake. Also significant hybrid by N interactions on leaf N, P and K were found.

D. Selection of a Yield Function

A comprehensive collection and review of related references to forms of production functions and data analysis for production function estimation by Heady and Dillon (1961) obviates that need here. Many forms of yield equations have been used to describe the effects of applied fertilizer on corn yields [see, for example, Chapters 14 and 15 of Heady and Dillon (1961)]. However, the quadratic equation or a modification of it, such as a mixed square root model, appears to fit as well or better than logarithmic and exponential functions. Walker (1961) used the quadratic equation to adequately describe nutrient uptake in grass as influenced by N, P and K fertilizer.

A major contribution to the use of the quadratic yield equation for estimating quadratic surfaces has been the central composite design proposed by Box and Wilson (1951) and by Box (1954). The central composite design has the advantage of ease of fitting by least squares analysis and a reduced

number of treatment combinations that are required to estimate a quadratic surface.

III. EXPERIMENTAL PLANS AND PROCEDURES

Only limited information on the effect of N, P and K in combination and at various rates on the yield of corn is available. Since agricultural production is becoming more intensive and production economics has supplied the basic tools for economic interpretation of multi-rate and multi-variable fertilizer experiments, it is imperative that more experimentation be carried out in this area.

Advances in statistics have led to the development of more efficient experimental designs which reduce the number of treatment combinations required for the estimation of important effects. These designs make it possible to conduct more experiments with similar resources than could be conducted by using complete factorial designs.

Past experimentation has brought out differences in the response of corn to applied fertilizers because of soil, weather or certain cultural conditions. The purpose of this experimentation is to determine the response of corn to applied nutrients and the effect of uncontrolled variables such as weather and soil on this response.

A. Experimental Sites and Procedures

Six multi-rate N-P-K fertilizer experiments with corn were conducted on cooperating farmer's fields in 1959 and twelve in 1960. The names and locations of the cooperators appear

in Table 49 in the Appendix.

The 18 experimental sites were located on the Clarion, Nicollet and Webster soil series in central and north central Iowa. Requirements for the sites were as follows: second year corn, no fertilization, i.e., no manure or commercial fertilizer since the crop grown the previous year, a soil test of low or very low for phosphorus or potassium and a uniform site as to slope and drainage.

The fertilizer sources were ammonium nitrate for N, concentrated superphosphate for P and muriate of potash for K. The rates and combinations presented in the next section were mixed and handspread on plots that were 13 1/3 feet by 40 feet in size. This size of plot allowed four rows spaced at distances of 40 inches. The fertilizer was spread on the corn stubble from the previous year and plowed under. The co-operator's normal cultural practices were allowed throughout the rest of the crop season. Cultural practices included preparation of seed bed, planting date, selection of hybrid, planting rate (cooperators were encouraged to plant at least 16,000 kernels per acre) and cultivation.

Aid was given to the cooperator to control weeds and corn borers. Control of corn borers of the first brood was effected by application of granular DDT. Hand pulling and hoeing aided farmer cultivation in the control of weeds so that there would be no need to consider this factor in subsequent analysis of the data.

Prior to fertilizer applications soil samples were taken from each replication in 6-inch increments to 24 inches in depth and a 12-inch increment from 24 to 36 inches in depth. Each sample consisted of from 10 to 12 composited borings. Determinations for pH, initial nitrate, nitrifiable N (on moist and dry samples), available P and exchangeable K (moist and dry) were made on all soil samples by the Iowa State University Soil Testing Laboratory according to methods described by Hanway and Heidel (1952). Soil test results are given for each replicate in Table 50 in the Appendix.

Samples for moisture determination were taken in 1-foot increments to 5 feet in depth as near the time of plant emergence as was possible. Rainfall gauges were installed at this time as near the experimental site as was feasible. The cooperator kept a record of daily rainfall throughout the growing season. The amount and distribution of weekly rainfall is listed in Appendix Table 51. Moisture characteristics of the soil that were measured are soil moisture at the time of sampling, wilting point by the pressure plate method at 15 atmospheres pressure and field capacity by a pressure apparatus under $1/3$ atmosphere pressure. The results of these measurements are presented in Appendix Table 52.

Leaf samples were taken when 75 percent of the plants in each experiment showed silks. The leaf opposite and below the primary ear shoot was taken from twenty plants in each

plot. These were dried to constant weight and ground for subsequent chemical analysis.

Corn yields were estimated by hand harvesting and weighing the corn from the center two rows of each plot approximately 35 feet long. Shelled corn samples were taken in the field from individual plots and weighed before and after drying to constant weight for determination of the moisture content. Yields were then calculated in bushels of shelled corn per acre at a common 15.5 percent moisture level (No. 2 corn) using a standard conversion table.

Stand counts were made at harvest time on each plot. These figures are included with yield and foliar composition in Appendix Tables 53 and 54.

B. Chemical Analysis

As previously mentioned the leaf samples were dried and ground in preparation for chemical analysis. Before the subsamples were weighed, the tops of the glass bottle containers were removed, and each sample was oven dried for 24 hours at 65° C. After each sample was dried and weighed, it was analyzed for N, P and K according to the procedure presented by Walker (1961). In this procedure a 0.5-gram sample is digested in boiling concentrated sulfuric acid. After the digested sample was diluted to a specified volume, aliquots were taken for determination of each element.

The N determination consists of detecting the concentra-

tion of N in the form of ammonium sulfate in the digest solution. A yellow color is produced upon alkalization with Nessler's reagent. The sample concentration is then determined by comparing the sample color with standards on a colorimeter.

The P concentration was determined by comparing samples and standards on a colorimeter in the presence of an added acid vanado-molybdate solution.

Determination of K was made using a flame photometer on an aliquot of the digest solution diluted with a lithium nitrate solution as an internal standard. The flame photometer was calibrated with standard solutions of known K concentration.

C. Weather Characterization

It is recognized that air temperature affects plant growth in a variety of ways. The two processes that may be indirectly measured by yield are the effects of temperature on some or all physiological processes of the plant and on water utilization as measured by evapotranspiration. It was observed during the seasons of 1959 and 1960 that temperature did not deviate appreciably from normal seasonal temperatures. Very few days exceeded 90° F and no exceptionally cool periods occurred. Therefore, it was decided that using temperature as a weather variable would not account for any appreciable

yield variation.

The soils used for this experimentation hold approximately 2 inches of available moisture per foot. Unless the corn plants were placed under some condition of moisture stress so that they would be entirely dependent upon precipitation, a good correlation between yield and precipitation would not be expected. Also, since the degree of weather effect depends on the occurrence of certain features of weather in relation to the stage of plant growth, it would be necessary to divide the growth season into numerous periods.

It was decided to characterize weather in a manner which shows a deficiency of moisture or a moisture stress situation for each experiment. This method results in a "stress day" criterion which means that when the available soil moisture in the root zone is depleted to a certain percentage of the available soil moisture capacity, that day is designated as a "stress day".

Moisture depletion under corn is the primary estimate to be made and the method of Shaw (1961) was used. The basic measurements needed are available moisture capacity of the soil, available soil moisture at time of planting, precipitation at the experimental site, estimation of rate of root extension in terms of depth, and open pan evaporation which is an integration of atmospheric conditions.

The calculation of available moisture in the root zone

involved adjusting, throughout the season, the available soil moisture at planting time for loss due to evaporation and evapotranspiration and gain by precipitation. Open pan evaporation for the respective site areas was obtained from the records of Shaw.¹ This was used to calculate the amount of evapotranspiration in inches of moisture for each day.

Assumptions were made regarding the presence of moisture in excess of field capacity, the removal of moisture from the soil and rate of root extension. Moisture in excess of field capacity was assumed to percolate on through the soil profile and did not provide a source of moisture to the corn. Moisture removal was assumed to be from the surface downwards and moisture supplied to the surface horizon by precipitation was assumed to be removed before moisture in the lower horizons. The rate of root extension, although dependent on factors such as soil temperature, soil moisture, aeration and nutrient supply, was assumed to be 6 inches per 2 weeks to one foot in depth and 6 inches per week to 5 feet. Water removal below 5 feet was not considered.

The starting date for each experimental site depended on the planting date. Therefore the calendar date varied considerably among experiments for similar stages of development. A growing period of 18 weeks or 126 days, starting from the

¹Shaw, Robert H. Unpublished data. Iowa Agr. Exp. Sta. Private communication. 1962.

planting date, was used. This length of growing period is similar to that used by Runge and Odell (1958) and Fitts et al. (1959).

The designation of a "stress day" is dependent on the criterion used. Several criteria were used to determine which gave the best correlation between check yields¹ and weekly totals of stress days. Also the stress days were accumulated into stress periods based on the physiological stage of development of the corn. This allowed weather characterization in as few variables as possible so that other yield affecting variables could also be evaluated.

D. Statistical Methods

The statistical design selected for the individual experiments was a central composite design plus a check plot not part of the design. This design requires fewer treatment combinations than other designs to obtain a yield function describing the effects of the fertilizer variables and allows experimentation over a wider range of soil and weather conditions. The treatment rates and combinations used in 1959 and 1960 are presented in Table 1. It is noted that a 5 x 5 x 5 N, P and K composite design was used. Four treatment combinations were added to the 1959 design for the 1960 experi-

¹Yields obtained without the addition of fertilizer will be designated as check yields.

Table 1. Treatment rates in pounds per acre and combinations with corresponding treatment number used for 1959 and 1960 experiments

| 1959 | | | | 1960 | | | |
|------------------|-----------------|------|------|------------------|-----------------|------|------|
| Treatment number | Fertilizer rate | | | Treatment number | Fertilizer rate | | |
| | N | P | K | | N | P | K |
| 1 | 40 | 17.4 | 20.8 | 1 | 40 | 17.4 | 20.8 |
| 2 | 40 | 17.4 | 62.2 | 2 | 40 | 17.4 | 62.2 |
| 3 | 40 | 52.4 | 20.8 | 3 | 40 | 52.4 | 20.8 |
| 4 | 40 | 52.4 | 62.2 | 4 | 40 | 52.4 | 62.2 |
| 5 | 120 | 17.4 | 20.8 | 5 | 120 | 17.4 | 20.8 |
| 6 | 120 | 17.4 | 62.2 | 6 | 120 | 17.4 | 62.2 |
| 7 | 120 | 52.4 | 20.8 | 7 | 120 | 52.4 | 20.8 |
| 8 | 120 | 52.4 | 62.2 | 8 | 120 | 52.4 | 62.2 |
| 9 | 80 | 35.0 | 41.6 | 9 | 80 | 35.0 | 41.6 |
| 10 | 0 | 35.0 | 41.6 | 10 | 0 | 35.0 | 41.6 |
| 11 | 160 | 35.0 | 41.6 | 11 | 160 | 35.0 | 41.6 |
| 12 | 80 | 0.0 | 41.6 | 12 | 80 | 0.0 | 41.6 |
| 13 | 80 | 69.8 | 41.6 | 13 | 80 | 69.8 | 41.6 |
| 14 | 80 | 35.0 | 0.0 | 14 | 80 | 35.0 | 0.0 |
| 15 | 80 | 35.0 | 83.0 | 15 | 80 | 35.0 | 83.0 |
| 16 | 0 | 69.8 | 83.0 | 16 | 0 | 0.0 | 83.0 |
| 17 | 160 | 0.0 | 83.0 | 17 | 0 | 69.8 | 0.0 |
| 18 | 160 | 69.8 | 0.0 | 18 | 0 | 69.8 | 83.0 |
| 19 | 0 | 0.0 | 0.0 | 19 | 160 | 0.0 | 0.0 |
| | | | | 20 | 160 | 0.0 | 83.0 |
| | | | | 21 | 160 | 69.8 | 0.0 |
| | | | | 22 | 160 | 69.8 | 83.0 |
| | | | | 23 | 0 | 0.0 | 0.0 |

ments. These additions removed intercorrelation between the linear regression terms and interaction terms containing like variables. The elimination of intercorrelation was accomplished in the inverse matrix where the correlation elements between the linear and interaction components were reduced to zero in 1960. This allowed the independent estimation of the respective coefficients and reduction in treatment sum of squares due to the respective regression term. The coded X matrix and the inverse matrix for the designs used in both years are presented in Appendix Tables 55, 56, 57 and 58.

Analysis of variance was calculated for each experiment to ascertain treatment effect and replication differences on grain yields and N, P and K percentages in the corn leaves. The effect of stand on grain yields was determined by analysis of covariance for each experiment. A combined analysis of variance over all experiments for each year was calculated for grain yields and leaf N, P and K percentages.

Multiple regression analysis was used for each replication in each experiment to ascertain the effects of applied N, P and K on grain yields and N, P and K percentages. The multiple regression techniques used in this text follow, in general, those procedures set up by Anderson and Bancroft (1952), Kempthorne (1952) and Snedecor (1956). Since those individual regression equations were in terms of the coded X matrix, they were decoded into terms of pounds of elemental

N, P and K. No attempt was made to delete terms from the individual regression equations on the basis of tests of statistical significance of the individual regression coefficients.

Discussion will be limited to the effect of applied N, P and/or K as determined by the statistical significance level of the respective regression coefficient. The probability level chosen was 0.30 for ascertaining whether a regression coefficient differed from zero. The t-value required for the t-test was slightly greater than one at this probability level.

The t-test criterion was used for individual regression coefficients because an F-ratio with one degree of freedom in the superscript is the same as the square of the t-test if the degrees of freedom in the subscript of the F-test are the same as the error degrees of freedom of the t-test.

The effects of all factors affecting yield and foliar composition and the magnitude of these effects was determined by multiple regression equations¹ involving each individual observation from the 18 experiments. Factors were deleted from this final equation on the basis of a t-value less than one if that factor had not been excluded on the basis of previous criteria.

¹These final multiple regression equations were fitted to the data by use of the IBM 650 computer in the Iowa State University Statistical Laboratory.

1. Selection of factors affecting the check yield and check leaf content

According to the work of Gomez (1960) the magnitude of the check yield determines to some extent the response to applied fertilizer, i.e., the larger the check yield the larger the response to applied fertilizer. The determination of the effect of the uncontrolled factor¹ on check yields should help explain variation in total yield obtained with applied fertilizer.

All factors other than applied fertilizer were evaluated for their effect on check yields and check leaf composition. These uncontrolled factors were stand level, planting date, nitrifiable soil N, soluble soil P, exchangeable soil K, soil pH, yield potential (a measure of the effect of each hybrid), stress periods and wind-storm damage.

The general procedure for determining the factors which affected check yield was performed in three steps. The check yields were plotted against each factor to determine visually whether the relationship (if any) was linear or curvilinear or if an interaction between uncontrolled factors was present. The second step involved the calculation of simple correlation coefficients for the linear relationships. Curvilinear relationships were determined if present. The third step

¹Uncontrolled factors in this text refers to any factor other than the applied fertilizer variables, which were considered to be independent variables.

involved calculating a multiple regression equation with all uncontrolled factors as independent variables and check yield as the dependent variable. Factors which did not attain a probability level of 0.30 for the simple relationship or in the multiple relationship were deleted from further consideration.

Similar procedures were separately performed for the check N, P and K percentages. The factors which were retained were used in evaluating their effects on response to N, P and K by yield and leaf composition.

2. Selection of uncontrolled-controlled factor relationships affecting yield

When field experimentation is conducted over a range of uncontrolled factors, the problem of evaluating the effect of these factors on the response of the crop to the applied factors exists. An analysis of variance of the observed yields will indicate whether the uncontrolled factors affect the yield response to the treatments (often shown by a treatment x location interaction). The location term includes the combined effect of all uncontrolled factors and this term alone in an analysis of variance indicates whether total yield varies among locations.

If only level of yield differs among locations then the effects of the uncontrolled and controlled factors are additive. However, when a treatment x location interaction

indicates uncontrolled-controlled factor relationships, the effects of these factors are no longer additive. Also, this does not indicate which specific relationship is causing this effect or what the effect is.

Multiple regression has proved to be a useful tool in bringing out these relationships and in estimating the effect of these same relationships. However, there is no general agreement as to the method to use in ascertaining what relationships should be entered in the multiple regression equation. A method was devised to ascertain which uncontrolled-controlled factor relationships were present in the experimentation conducted for this dissertation.

a. Development of fundamental concepts Yields may be described as a function of some added factor increased from some base level, which may be zero, or as some decrement from an optimum level which may or may not be known. All factors, controlled and uncontrolled, are assumed to be increasing from some base level in this development. Another basic assumption is that response to the controlled factor is decreasing at an increasing rate.

The yield limiting factor or factors determine the yield level obtained from a given set of factors and consequently the decreasing returns to the controlled factor. Among the yield limiting factors is the genetic potential of the crop. However, it is difficult to ascertain this

potential and therefore the controlled factors are varied in an attempt to obtain some maximum yield or some yield approaching a maximum. The total effects of uncontrolled factors affecting total yield and the response to the controlled factor at one location are assimilated into a yield equation as a function of the controlled factor. Unless different levels of uncontrolled factors are encountered, the effects of these on the yield response to the controlled factor cannot be singled out. If different levels of uncontrolled factors affect the effect of the controlled factor on yield, the yield equations describing yield as a function of the controlled factor will differ.

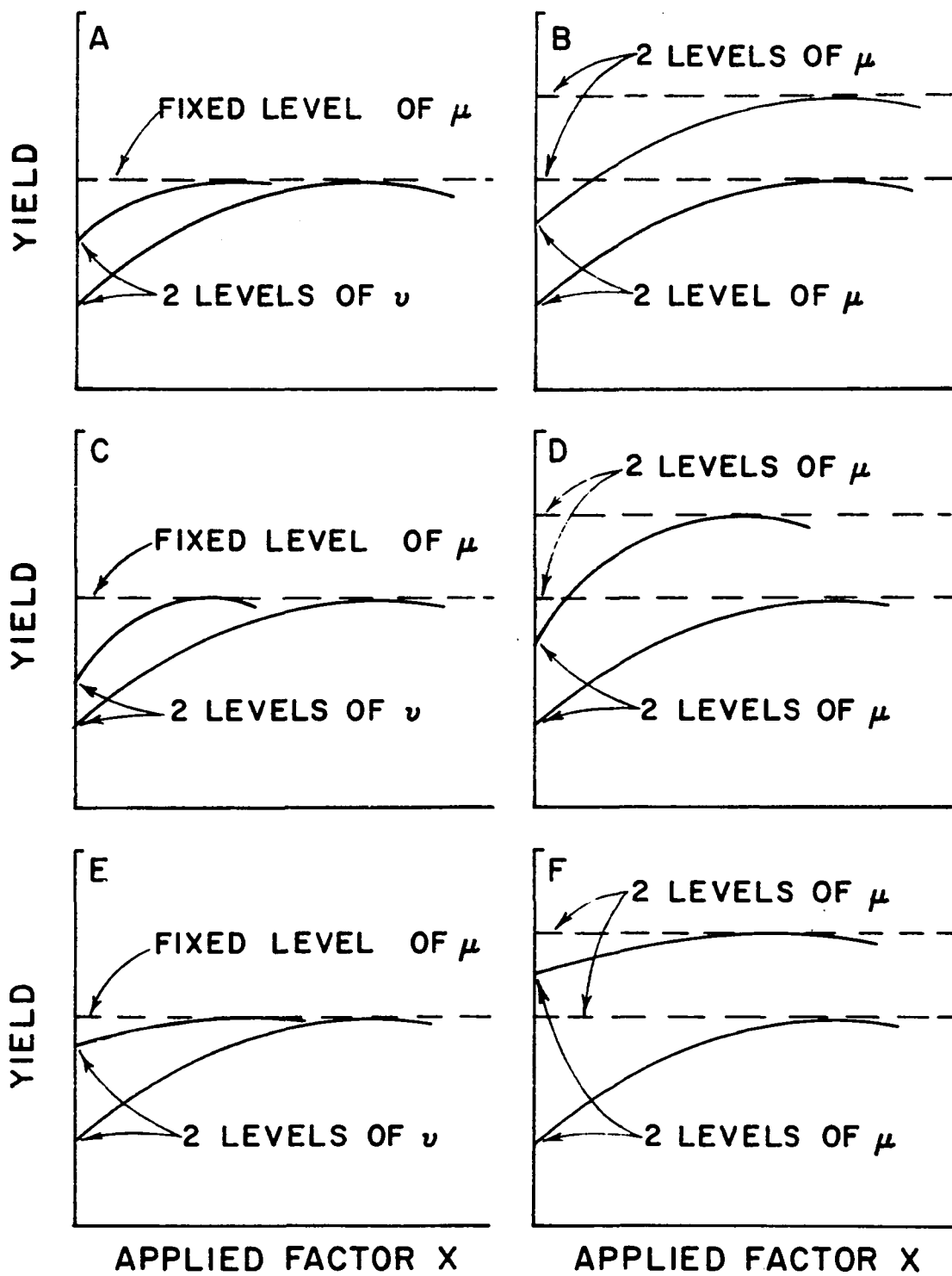
For purposes of clarification and illustration the quadratic yield function,

$$Y = b_0 + b_1 X + b_{11} X^2,$$

is used. If X is the controlled factor, b_0 is the yield obtained due to the uncontrolled factors alone. The linear term b_1 designates the linear response to the controlled factor X at the origin (point where b_0 is measured) and the second degree term b_{11} denotes the rate of curvature as the yield function approaches the maximum yield for the case in question.

b. Illustration of concepts Let u and v be uncontrolled factors where used, X the controlled variable and Y the yield. Various theoretical yield functions obtained at two levels of u and v are illustrated in Figure 1. The

Figure 1. Hypothetical relationships between quadratic yield functions, describing yield as a function of the applied factor X , and different levels of uncontrolled factors u and v



relationships between the uncontrolled factors and X is pointed out in the following cases.

Case 1. Consider Figure 1A where the yield limiting factor u is at a fixed level. The uncontrolled variable v is at two levels and does not affect the linear terms of the two functions but does increase the check yield. The second degree term becomes more negative as v increases. Interpretation: v and X are additive in their effect on yield. v and the second degree coefficient are negatively correlated which may or may not indicate that another factor is limiting yield.

Case 2. Consider Figure 1C where the yield limiting factor u is at a fixed level. The uncontrolled variable v is at two levels and as it increases in value, the check yield increases as does the value of the linear coefficient. The second degree term becomes more negative as v increases. Interpretation: The response to X increases as v increases, i.e., a positive interaction is present. v and the second degree coefficient are negatively correlated indicating that another factor may or may not be limiting yield.

Case 3. Consider Figure 1E where the yield limiting factor u is at a fixed level. The uncontrolled variable v is at two levels and as it increases in value the check yield increases whereas the linear coefficient decreases in value. The second degree term may increase, decrease, or not change in value depending on the degree of change of the other

relationships. Interpretation: The response to X decreases as v increases showing a negative interaction to be present. The relationship between v and the second degree term is indeterminate.

Case 4. Consider Figure 1B where the yield limiting factor u is the only uncontrolled variable and is at two levels. An increase in u does not affect the linear terms but does increase the check yield. The second degree term may increase, decrease, or not change in value depending on the degree of change in the check yield and yield level allowed by u. Interpretation: u and X are additive in their effect on yield. If u and the second degree coefficient are positively correlated or uncorrelated (with the positive change in check yield in mind), this indicates u is a yield limiting factor.

Case 5. Consider Figure 1D where the yield limiting factor u is at two levels. As u increases the check yield increases in value as does the linear coefficient. The second degree coefficient may increase, decrease or not change in value. Interpretation: The response to X increases as u increases, i.e., a positive interaction is present. If u and the second degree coefficient are positively correlated or uncorrelated (with the positive increase in check yield and increase in linear coefficient value), this indicates u is a yield limiting factor.

Case 6. Consider Figure 1F where the yield limiting factor u is at two levels. As u increases the check yield increases and the linear coefficient decreases in value. The second degree coefficient may increase, decrease or not change in value. Interpretation: The response to X decreases as u increases, i.e., a negative interaction is present. The relationship between u and the second degree term is indeterminate.

These illustrations show that uncontrolled factors affect the yields obtained from application of the controlled variable. These changes in yields are reflected in the terms of the yield function. The changes in the terms of the yield function provide a useful estimate of the effects produced by changes in the uncontrolled variables. The effect of the uncontrolled-controlled factor relationship on yield can be shown by a multiple regression equation over all experiments or locations. The selection of these uncontrolled-controlled factors is based on the concepts set forth above.

c. Method of detecting relationships Although the uncontrolled-controlled factor relationship may be deduced from direct examination of the quadratic equation regression coefficients and uncontrolled factor measurements, it is difficult to ascertain these relationships when numerous multi-variable yield functions and corresponding uncontrolled multi-factor measurements are involved. This difficulty may

be resolved by calculating the degree of relationship through simple correlation and regression. The slope of the simple regression line indicates the sign and magnitude of the interaction between the controlled and uncontrolled factors. That the slope of this line is the interaction may be ascertained as follows: a linear coefficient $b_1 = (\text{unit change in } Y) / (\text{unit change in controlled variable})$; the slope of the above mentioned regression line has the units, $(\text{unit change in } Y) / (\text{unit change in controlled factor})(\text{unit change in uncontrolled factor})$, which is the algebraic form of such an interaction term.

The insertion of these uncontrolled-controlled factor terms into an overall second degree regression equation should allow the flexibility necessary for describing the effects obtained and aid in the interpretation of the observed results.

IV. RESULTS AND DISCUSSION

Corn yield and leaf N, P, and K content responded by various degrees to applied N, P, and K. The response of corn yield was greatest to N, whereas the effects of applied P and K were not consistent. Leaf content varied primarily due to the respective fertilizer nutrient. Many factors affecting the respective responses to applied fertilizer were apparent. However, due to the amount and nature of the data it was not easy to ascertain which factors were affecting yield or the yield response to the fertilizer. The factors selected and the method of selection as well as the nature of the factor effects are discussed in the following sections.

A. Corn Yield

The yield of corn was affected by soil, weather, fertilizer, management and the interaction of components of these factors. Factors affecting corn yield, other than applied fertilizer, were selected initially on the basis of their effect on corn yields obtained with zero fertilizer applied.

Weather was characterized into a stress day criterion instead of using the usual components of rainfall and temperature. Soil factors considered were soil reaction and quantities of soil nutrients as measured by soil tests. Management factors such as corn hybrid, planting data and rate of

planting were also evaluated. These factors were then evaluated for their effect on the response of corn yield to applied N, P and K. The factors affecting corn yield and the methods of selecting these factors are discussed in succeeding paragraphs.

1. Selection of criteria for designation of stress days

The designation of any day in a growing season of 126 days as a stress day was dependent upon the percent of available moisture depleted in the root zone or a portion of the root zone. The available moisture in the root zone on any day was calculated by adjusting for additions due to rainfall and estimating the depletion of moisture according to the method of Shaw (1961). The amount of available moisture depletion necessary before a stress day was designated was determined by correlating the check yields from the eighteen experiments with the days in the stress periods.

Stress periods were divisions of the 18 week growing season into periods based on physiological development. Period 1, 5 weeks in duration, was from the date of planting to the time that the corn was approximately 24 inches in height. Period 2, 4 weeks in duration, covered the grand period of growth from 24 inches in height until approximately the beginning of tasseling. Periods 3 and 4, each 2 weeks in length, covered the period before and during early silking and the period during the latter stages of silking. Period 5, 5 weeks

in duration, entailed the remainder of the season.

The correlation of check yields with stress periods, containing stress days determined at various levels of soil moisture depletion, is shown in Table 2. Low correlations

Table 2. Simple correlation values showing the relationship of check yield with stress day periods and total stress days in the season

| Stress day criteria | Stress day period | | | | | Total stress days |
|--|-------------------|--------|--------|-------|-------|-------------------|
| | 1 | 2 | 3 | 4 | 5 | |
| 50% of available moisture depleted in root zone | -0.040 | -0.287 | -0.005 | 0.117 | 0.207 | 0.018 |
| 50% of available moisture depleted in root zone and surface foot | -0.043 | -0.287 | 0.000 | 0.169 | 0.201 | 0.000 |
| 60% of available moisture depleted in root zone | -0.180 | -0.370 | -0.049 | 0.161 | 0.208 | 0.006 |
| 60% of available moisture depleted in root zone and surface foot | -0.070 | -0.404 | -0.045 | 0.125 | 0.274 | -0.196 |

between check yields and stress periods made up of stress days during which the available moisture in the root zone was 50 percent or less are shown. The second criterion for stress days was 50 percent of available moisture depleted in the root zone and surface foot. This had little effect on the correlations of check yields with the stress periods. The third criterion for stress days was 40 percent or less available

moisture in the root zone. This criterion resulted in better correlations between check yields and stress periods than previous criteria. The fourth criterion examined was depletion of 60 percent or more of the available moisture in the root zone and surface foot. This resulted in an improved correlation for the second period or the grand period of growth, and this designation of a stress day is used in all subsequent analyses.

Check yields did not show a good relationship with total stress days for the entire season. This indicates that it is the distribution of these days that affects yields and not the total for the season.

The periods were redesignated so that only four periods covered the growing season. The new period classification eliminated period 4 from the previous classification by including one week in this period in the previous or silking period and the other week in the following or maturity period. The improvement in the relationship of check yield with the new period, period 3, during silking is shown in Table 3. This classification is used in all subsequent analyses of yield data. Table 4 lists the number of stress days occurring in each period for each experiment. The number of stress days per experiment varied from 0 to 73 days for the entire growing season. The 1959 experiments had more stress days on the average than the 1960 experiments because the 1959 soil

Table 3. Simple correlation values showing the relationship of check yield with four stress day periods (stress day designated when 60 percent of available moisture is depleted in the root zone and surface foot)

| Stress day period and length | | | |
|------------------------------|--------------|--------------|--------------|
| 1 5 weeks | 2 4 weeks | 3 3 weeks | 4 6 weeks |
| -0.070 | -0.404 | -0.192 | 0.144 |

Table 4. Stress days in stress periods and season total for each experiment

| Year and experiment | 1 | Stress day period 2 | 3 | 4 | Season total |
|------------------------|----|------------------------|----|----|-----------------|
| 1959 | | | | | |
| 1 | 18 | 10 | 17 | 13 | 58 |
| 2 | 7 | 11 | 21 | 17 | 56 |
| 3 | 16 | 9 | 19 | 23 | 67 |
| 4 | 20 | 4 | 0 | 1 | 25 |
| 5 | 1 | 0 | 0 | 6 | 7 |
| 6 | 14 | 0 | 0 | 17 | 31 |
| 1960 | | | | | |
| 1 | 5 | 0 | 0 | 21 | 26 |
| 2 | 1 | 24 | 21 | 22 | 68 |
| 3 | 3 | 0 | 0 | 15 | 18 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 |
| 7 | 15 | 28 | 17 | 13 | 73 |
| 8 | 0 | 0 | 7 | 6 | 13 |
| 9 | 8 | 15 | 20 | 25 | 68 |
| 10 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 |

profiles did not contain as much available moisture at time of planting. Moisture content of the 1960 profiles was at or near field capacity at planting.

Check yield was correlated with each week's stress days based on 60 percent depletion of available moisture in the root zone and in the surface foot, weekly rainfall and average weekly maximum temperature. The correlation values, presented in Table 5, show that check yield has a more consistent relationship with the stress day criterion and a better relationship during the stages of growth contained in periods 2 and 3 which include weeks 6 through 12.

2. Selection of soil variables

Soil samples were taken by increments in depth for chemical analysis. The soil variables were selected on the basis of simple correlation with check yield obtained from each replicate. As available soil N, P and K decreased steadily with depth, it was also determined whether check yields were related to the subsoils' supplies of these nutrients. Finally, the surface measurements of soil nutrients from 0 to 6 inches were related to the amounts measured from 6 to 36 inches to determine whether the surface measurements adequately indicated the soil profile's contribution of N, P and K.

The correlations of check yield with various soil test values are shown in Table 6. Check yield was related to nitrifiable N and exchangeable K measured on field moist

Table 5. Simple correlation values showing the relationship of check yield with weekly stress day and precipitation totals and average weekly maximum temperature

| Week | Stress day | Precipitation | Temperature |
|------|------------|---------------|-------------|
| 1 | 0.010 | -0.058 | 0.013 |
| 2 | -0.040 | 0.128 | -0.166 |
| 3 | 0.010 | 0.209 | 0.222 |
| 4 | -0.007 | -0.073 | -0.122 |
| 5 | -0.253 | 0.096 | 0.133 |
| 6 | -0.420 | 0.440 | -0.231 |
| 7 | -0.371 | -0.059 | -0.155 |
| 8 | -0.303 | 0.124 | -0.068 |
| 9 | -0.369 | -0.139 | -0.234 |
| 10 | -0.244 | 0.467 | -0.096 |
| 11 | -0.228 | -0.103 | -0.230 |
| 12 | -0.127 | 0.206 | 0.165 |
| 13 | 0.063 | 0.068 | 0.143 |
| 14 | 0.224 | -0.171 | 0.398 |
| 15 | -0.029 | 0.032 | 0.043 |
| 16 | 0.075 | 0.071 | 0.032 |
| 17 | 0.123 | -0.043 | 0.047 |
| 18 | 0.166 | 0.103 | 0.103 |

Table 6. Correlation values^a showing the relationship of check yield with surface soil test values and with selected soil test variables by depth

| Soil test variable ^b | Depth in inches | | | | |
|---------------------------------|---------------------|--------------------|--------|--------------------|---------------------|
| | 0-6 | 6-12 | 12-18 | 18-24 | 24-36 |
| Initial nitrate | -0.120 | | | | |
| Nitrifiable N (D) | 0.237 ⁺ | | | | |
| Nitrifiable N (M) | 0.381 [*] | 0.192 ⁺ | -0.094 | -0.114 | -0.139 |
| Available P (D) | 0.464 ^{**} | 0.392 [*] | 0.142 | 0.395 [*] | 0.488 ^{**} |
| Exchangeable K (D) | -0.103 | | | | |
| Exchangeable K (M) | 0.306 ⁺⁺ | 0.248 ⁺ | 0.166 | 0.172 | 0.141 |
| pH | 0.264 ⁺ | | | | |

^aSuperscripts denote probability level of statistical significance. Double asterisk denotes 0.01 level of significance. Single asterisk denotes 0.05, double cross denotes 0.10 and single cross 0.30 in this and all subsequent tables unless otherwise designated.

^bD and M designations refer to measurements made on air dry and field moist samples respectively.

samples. Check yield had the highest correlation with available P, and subsoil P was also related to yield. However, yield was not related to subsoil N or K. pH had a slight effect on yield.

That surface soil values from 0 to 6 inches for N, P and K were a good measure of the amount supplied by the whole profile is shown in Table 7. A highly significant correlation between the soil test for the plow layer and the remainder of the profile was obtained for N, P and K. This table also

Table 7. Correlation values relating surface soil test values and remainder of profile and intercorrelation of surface soil values

| Soil test variable ^a and depth in inches | Surface soil test variable ^a | | |
|---|---|-----------------|--------------------|
| | Nitrifiable N (M) | Available P (D) | Exchangeable K (M) |
| Nitrifiable N (M) | | | |
| 0-6 | 1.000 | -0.055 | -0.069 |
| 6-36 | 0.667** | | |
| Available P (D) | | | |
| 0-6 | | 1.000 | 0.506** |
| 6-36 | | 0.869** | |
| Exchangeable K (M) | | | |
| 0-6 | | | 1.000 |
| 6-36 | | | 0.881** |

^aD and M designations refer to measurements made on air dry and field moist samples respectively.

shows the degree of intercorrelation between these variables. Only soil P and K are significantly correlated, but this correlation is highly significant.

On the basis of these relationships only the soil test values from the surface increment of 0 to 6 inches were used as soil nutrient variables. The soil variables selected were nitrifiable N and exchangeable K measured on field moist samples, available P and pH. The soil test values are shown in Table 8. The range of these values in pounds per acre is from 46 to 109 for N, 0.5 to 13.4 for P and 48 to 320 for K. pH ranged from 6.10 to 8.10.

Table 8. Surface soil test values for each experiment and replicate

| Year, ex- periment and repli- cate | pH | Nitrifiable N lbs./acre | Available P lbs./acre | Exchangeable K lbs./acre |
|---|------|----------------------------|--------------------------|-----------------------------|
| <u>1959</u> | | | | |
| 1-1 | 6.35 | 74 | 1.5 | 93 |
| 1-2 | 6.40 | 76 | 1.4 | 88 |
| 2-1 | 6.70 | 67 | 4.6 | 72 |
| 2-2 | 7.80 | 107 | 4.1 | 70 |
| 3-1 | 6.65 | 65 | 2.5 | 83 |
| 3-2 | 6.60 | 71 | 2.9 | 84 |
| 4-1 | 6.75 | 73 | 6.4 | 58 |
| 4-2 | 6.40 | 72 | 4.9 | 72 |
| 5-1 | 8.00 | 87 | 0.9 | 71 |
| 5-2 | 8.10 | 94 | 4.1 | 77 |
| 6-1 | 6.65 | 109 | 12.2 | 140 |
| 6-2 | 6.55 | 91 | 8.1 | 109 |
| <u>1960</u> | | | | |
| 1-1 | 6.50 | 74 | 4.2 | 84 |
| 1-2 | 6.40 | 69 | 3.5 | 134 |
| 2-1 | 7.00 | 72 | 2.9 | 94 |
| 2-2 | 6.35 | 72 | 2.4 | 125 |
| 3-1 | 6.70 | 53 | 15.2 | 113 |
| 3-2 | 6.60 | 46 | 17.2 | 107 |
| 4-1 | 7.40 | 61 | 3.7 | 124 |
| 4-2 | 7.75 | 63 | 1.0 | 144 |
| 5-1 | 6.25 | 59 | 11.0 | 134 |
| 5-2 | 6.75 | 60 | 3.9 | 80 |
| 6-1 | 6.25 | 60 | 6.9 | 254 |
| 6-2 | 6.20 | 70 | 10.5 | 282 |
| 7-1 | 6.20 | 71 | 3.0 | 110 |
| 7-2 | 6.10 | 75 | 2.5 | 104 |
| 8-1 | 7.75 | 73 | 0.5 | 48 |
| 8-2 | 7.70 | 87 | 3.0 | 56 |
| 9-1 | 6.55 | 88 | 12.1 | 158 |
| 9-2 | 6.60 | 77 | 18.4 | 145 |
| 10-1 | 6.45 | 78 | 14.5 | 320 |
| 10-2 | 6.60 | 72 | 7.5 | 158 |
| 11-1 | 6.10 | 78 | 9.5 | 122 |
| 11-2 | 6.30 | 64 | 5.2 | 96 |
| 12-1 | 6.20 | 74 | 3.1 | 100 |
| 12-2 | 6.20 | 55 | 2.4 | 63 |

3. Selection of variables other than weather and soil

Other factors evaluated for their effect on yields which were obtained with no addition of fertilizer were stand (plant density), planting date and corn hybrid. Final stand was recorded from each plot at harvest and varied from 10,300 to 16,900 plants per acre on the check plots. Planting date was obtained from each cooperator and the earliest planting date, April 30, for the eighteen experiments was considered as zero. All subsequent planting dates were designated by the number of days from April 30 and varied from 0 to 38 days.

The cooperators were allowed free selection of a corn hybrid, so many different ones were used depending on the locale. In order to evaluate the effect of hybrid a quantitative measure of yielding ability of each hybrid in bushels per acre was used and designated as the yield potential. The source used for selection of the yield potential was records of the Iowa Crop Improvement Association.¹ The yields for each hybrid were obtained from the district containing the experiment or from an adjoining district if the hybrid was entered in that district. The yields for each hybrid were averaged over the years entered in the tests and these yields varied from 70 to 120 bushels per acre. The date of planting, hybrid planted and the yield potential are

¹Ingledue, R. D., Ames, Iowa. Data from the Iowa corn yield test. Private communication. 1962.

presented in Table 9.

Severe wind storm damage occurred in three experiments just prior to and during silking. These were 1960 Experiments 2, 7, and 12. This factor was coded as minus one for all yields obtained from these experiments and as zero for all other experiments.

The degree of correlation of check yield with stand, planting date, yield potential and wind damage is presented in Table 10. Yield had a highly significant positive relation with stand. The negative correlation of check yield with

Table 9. Planting date, hybrid and yield potential of hybrid in each experiment

| Year and experiment | Planting date | Hybrid | Yield ^a potential |
|---------------------|---------------|-----------------|------------------------------|
| <u>1959</u> | | | |
| 1 | May 18 | Pioneer 352 | 9.1 |
| 2 | May 8 | Pioneer 352 | 9.1 |
| 3 | May 15 | Berries 315 A | 10.4 |
| 4 | May 27 | Turner T-27 | 7.0 |
| 5 | May 18 | Funks 23 and 26 | 9.6 |
| 6 | May 25 | Pioneer 354 | 11.7 |
| <u>1960</u> | | | |
| 1 | May 5 | Cargill 385 | 10.4 |
| 2 | May 23 | Pioneer 354 | 11.4 |
| 3 | April 30 | Cargill 385 | 10.4 |
| 4 | May 24 | DeKalb 444 | 10.3 |
| 5 | May 16 | Funks 76 | 9.8 |
| 6 | May 18 | DeKalb 444 | 10.3 |
| 7 | May 29 | Pioneer 371 | 12.0 |
| 8 | May 21 | Pioneer 371 | 12.0 |
| 9 | May 30 | Pioneer 354 | 11.4 |
| 10 | May 30 | Pioneer 371 | 12.0 |
| 11 | May 30 | Pioneer 349 | 11.1 |
| 12 | June 7 | Steckleys 4 | 9.8 |

^aTens of bushels per acre.

Table 10. Correlation values relating check yield to stand, planting date, yield potential and wind damage factor

| | |
|-----------------|----------------------|
| Stand | 0.425** |
| Planting date | -0.281 ⁺⁺ |
| Yield potential | 0.196 ⁺ |
| Wind damage | 0.698** |

planting date indicates that check yield decreases as corn is planted later in the season. Check yield has a minor positive relationship with yield potential. Check yield had a highly significant correlation with the wind damage factor indicating that this adjustment accounts for a large degree of the yield depression in the three experiments. All four of these factors were retained for subsequent analysis.

4. Combined effect of uncontrolled variables on check yield

The purpose of the previously described graphical and correlation analyses was to ascertain which variables accounted for variation in the check yields. These variables and appropriate interactions were utilized in a multiple regression analysis to ascertain the amount of variation in check yields accounted for by these variables and, thereby, to obtain an indication of the validity for selection of these variables.

Indication of an interaction was obtained by plotting check yields against each uncontrolled factor. If yields are not randomly grouped around a simple regression line and more than

one relationship seems possible, an interaction is indicated. These separate relationships were identified with another variable if possible, and an analysis of covariance was calculated according to the methods of Snedecor (1956). If the two apparent regression lines were significantly different, these interactions were entered into the multiple regression equation.

Variates which had a significance at a probability of 0.30 as determined by a t-test for the simple or multiple relationship were retained in the multiple regression equation. The multiple regression equation variates and values of the regression coefficients are presented in Table 11. This table also shows singular relationships of check yield with the variates through simple correlation values. An R^2 -value of 0.823 was obtained for this regression equation containing 17 variables. The regression mean square was highly significant.

This regression equation had only three terms that attained some level of significance although the equation was highly significant. This indicates that factors, although contributing to check yield, did not do so in a consistent manner. The range of check yield was from 46.5 to 111.2 bushels per acre.

A cursory examination suggests that the linear coefficients of soil N and P, yield potential, stress period 1 and stress period 2 have signs opposite to that normally expected.

Table 11. Regression of check yield on observed variates, significance level of regression coefficients and correlation values and their significance obtained from relating check yield to each variate

| Variate ^a | Equation $\hat{Y} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{yx_i} \cdot x_j^b$ |
|---------------------------------|--|--|------------------------|
| | 164.1000 ^c | | |
| N _S | -1.4475 X ₁ | | 0.381* |
| P _S | -5.4783 X ₂ | + | 0.464** |
| K _S | +0.0226 X ₃ | | 0.306 ⁺⁺ |
| pH | -0.0848 X ₄ | | 0.264 ⁺ |
| P _S x pH | +0.6538 X ₅ | | 0.493** |
| S | +0.2384 X ₆ | | 0.425** |
| S ² | +0.0519 X ₇ | | 0.398* |
| T | -0.2034 X ₈ | | -0.281 ⁺⁺ |
| Y | -10.3298 X ₉ | | 0.196 ⁺ |
| N _S x Y | +0.1613 X ₁₀ | | 0.412* |
| P _S x Y | +0.1683 X ₁₁ | ++ | 0.537** |
| W | +19.3527 X ₁₂ | * | 0.698** |
| D ₁ | -0.1263 X ₁₃ | | -0.070 |
| D ₂ | +0.7891 X ₁₄ | | -0.404* |
| D ₃ | +0.0567 X ₁₅ | | -0.192 ⁺ |
| D ₁ x D ₂ | -0.0012 X ₁₆ | | -0.257 ⁺ |
| D ₂ x D ₃ | -0.0476 X ₁₇ | | -0.278 ⁺ |

^a Hereinafter these symbols will be used in subsequent tables. Soil N is designated by N_S, soil P by P_S, soil K by K_S, stand by S, planting date by T, yield potential by Y, wind damage factor by W and stress periods by D, i.e., stress period 1 by D₁.

^b $b_{i,j} = 1 \dots 17. \quad i \neq j.$

^c This is b₀, the constant in the regression equation.

However, these linear coefficients are the slopes of these variables at an origin of zero and therefore are not the slopes of the effect of these variables within the relevant range of the observations. The effect of each of these variables is dependent on other variables and, therefore, the change in yield due to a variable that is also in an interaction is dependent on the level of the other variable in the interaction term and the value of its coefficient.

The regression coefficient and correlation coefficient of stress period 1 were not significant at any level but was retained in the regression equation because it appears in an interaction term. Such terms were retained in all regression analyses for two reasons. The chosen function remains continuous with respect to the term in question and interpretation of the effect of a factor in an interaction cannot be conclusively made unless the linear effect is also present.

The value of this equation is not in the equation itself but in the selection of terms affecting check yield for future analyses. The effect that these factors may have on total yield or on the change in yield due to applied N, P and K is of primary importance.

5. Effect of applied N, P and K

The presence of treatment effect on yields from each experiment was determined by a simple analysis of variance for each experiment. The analysis of variance for each 1959

experiment is presented in Table 12 and for each 1960 experiment in Table 13.

Table 12. Analysis of variance of yield for each of six experiments conducted in 1959

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|----------------------|----------------------|
| | | 1 | 2 | 3 |
| Total | 37 | | | |
| Replicates | 1 | 125.65 ⁺ | 564.03 [*] | 428.48 [*] |
| Treatments | 18 | 334.00 ^{**} | 207.80 [*] | 354.00 ^{**} |
| Error | 18 | 46.87 | 76.20 | 75.12 |
| | | 4 | 5 | 6 |
| Total | 37 | | | |
| Replicates | 1 | 189.24 ⁺⁺ | 300.73 ^{**} | 66.84 ⁺ |
| Treatments | 18 | 86.33 ⁺ | 146.97 ^{**} | 65.76 ⁺⁺ |
| Error | 18 | 49.11 | 27.39 | 29.82 |

Treatment effect attained a probability level of 0.01 in 1959 Experiment 1, 3 and 5, 0.05 in Experiment 2, 0.10 in Experiment 6 and 0.30 in Experiment 4. Treatments did not affect stand although stand did affect yield in some experiments. Experiments 1, 3 and 4 were adjusted for stand differences by an analysis of covariance but the probability levels for treatments did not change. The apparent reason for little treatment effect in Experiment 4 was the low stand level. An average stand of only 12,600 plants per acre was harvested

Table 13. Analysis of variance of yield for each of twelve experiments conducted in 1960

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|-----------------------|----------------------|
| | | 1 | 2 | 3 |
| Total | 45 | | | |
| Replicates | 1 | 297.58 ⁺ | 24.69 | 80.37 |
| Treatments | 22 | 229.19 ⁺⁺ | 157.19 ⁺ | 354.46 ^{**} |
| Error | 22 | 128.32 | 118.72 | 74.99 |
| Total | 45 | <u>4</u> | <u>5</u> | <u>6</u> |
| Replicates | 1 | 466.57* | 1287.90 ^{**} | 312.52 ⁺ |
| Treatments | 22 | 443.98 ^{**} | 562.40 ^{**} | 484.99 ^{**} |
| Error | 22 | 64.77 | 124.23 | 117.37 |
| Total | 45 | <u>7</u> | <u>8</u> | <u>9</u> |
| Replicates | 1 | 0.55 | 10.43 | 189.65* |
| Treatments | 22 | 112.39 ⁺ | 246.06 ^{**} | 44.98 ⁺ |
| Error | 22 | 66.62 | 86.21 | 31.18 |
| Total | 45 | <u>10</u> | <u>11</u> | <u>12</u> |
| Replicates | 1 | 265.92* | 12.00 | 274.16* |
| Treatments | 22 | 147.53 ^{**} | 172.29 ^{**} | 443.55 ^{**} |
| Error | 22 | 48.90 | 61.11 | 63.13 |

in this experiment. Corn in Experiment 6 responded to treatment but the effect was not large. An initial fertility level in the medium range as shown by the soil test values in Table 8 probably limited treatment effect.

Difference between replicates is noted in Table 12 for the 1959 experiments. Some of these differences may be attributed to soil fertility differences between replicates as in Experiments 2 and 5. Adjustment for stand by covariance decreased the significance level for replicates in Experiment 4.

The treatment effect attained a probability level of 0.01 in 1960 Experiments 3, 4, 5, 6, 8, 10, 11 and 12, 0.10 in Experiment 1 and 0.30 in Experiments 2, 7 and 9 as shown in Table 13. Fertilizer treatment did not affect stand, but stand affected yields in Experiments 1, 3, 5, 6, 7, 10 and 12. Adjustment by covariance for stand increased the probability level of treatment effect in Experiment 7 from 0.30 to 0.01 but decreased it from 0.10 to 0.30 in Experiment 1 and from 0.01 to 0.10 in Experiment 10. Since stand counts were obtained from individual plots, it was used in later analysis as an independent variable affecting yield.

The stand level in Experiment 7 in 1960 was very erratic among plots. This was shown by the increase in treatment effect after adjustment for stand. Treatment had little effect on yields in Experiments 1, 2 and 9 after adjustment for

stand. The stress days occurring during critical periods of growth coupled with high average stand levels of 17,000 in each experiment affected responses in Experiments 2 and 9. No apparent explanation is available for the lack of treatment effect in Experiment 1. Experiment 10 responded some to treatment but as shown in Table 8 the high initial soil fertility level in P and K probably restricted response to some degree.

No replicate differences were obtained in 1960 Experiments 2, 3, 7, 8 and 11. Although no individual replicate measurements were made, other than the soil test determinations, most of the replicate differences were attributed to initial soil fertility. Evidence for this may be obtained in Table 8. A sizeable difference in either soil N, P or K is present for those experiments having replicate differences. Thus, in order to better evaluate the effect of initial soil N, P and K on the response to applied N, P and K individual observations were used for future analyses, and the effect of applied N, P and K was obtained through analysis of yields by individual replicates for each experiment.

The preceding analyses indicated different effects of treatments among experiments. A combined analysis of variance for the 1959 experiments shown in Table 14 further substantiates this inference for that year. The yield among experiments differed as shown by the 0.01 probability level

Table 14. Combined analysis of variance of yield for 1959 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|-------------|
| Total | 227 | |
| Experiments | 5 | 2862.15** |
| Treatments/Experiments | 108 | 199.14 |
| Treatments | 18 | 596.17** |
| Treatments x Experiments | 90 | 119.73** |
| Replicates/Experiments | 6 | 279.16 |
| Replicates | 1 | 876.36 |
| Replicates x Experiments | 5 | 159.72 |
| Error | 108 | 50.75 |

for experiments. The treatments x experiments mean square is also highly significant and this indicates variation in the responsiveness to treatments among experiments. The mean square for treatments when compared to the mean square for treatments x experiments is also significant at the 0.01 probability level. This indicates consistent differences among treatments. The pooled error terms are homogeneous according to Bartlett's procedure presented by Snedecor (1956). The interaction of treatments x experiments are assumed to be homogeneous.

The combined analysis of variance for the 1960 experi-

ments appears in Table 15. These results are similar to those obtained in 1959 and the same conclusions indicated. However, the pooled errors from the individual analyses of variance were heterogeneous for 1960. This leaves the probability level for the significance of the treatment x experiments term in doubt. By assuming the highest tabulated F-value for this comparison at a single experiment's degrees of freedom of 22 and 22 it attains a probability of 0.10. If the pooled errors were homogeneous, the probability level would be 0.01. Therefore the true probability level for the treatments x experiments interaction is between 0.01 and 0.10.

Table 15. Combined analysis of variance of yield for 1960 experiments

| Source of variation | Degrees of freedom | Mean squares |
|--------------------------|--------------------|---------------------|
| Total | 551 | |
| Experiments | 11 | 7715.17** |
| Treatments/Experiments | 264 | 283.21 |
| Treatments | 22 | 1724.58** |
| Treatments x Experiments | 242 | 152.18 ^a |
| Replicates/Experiments | 12 | 269.43 |
| Replicates | 1 | 1197.41 |
| Replicates x Experiments | 11 | 184.16 |
| Error | 264 | 82.16 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for this variance comparison cannot be ascertained. At 22 and 22 degrees of freedom it attains a significance level of 0.10.

Considerable evidence indicating response to treatments, difference in the response among experiments and difference in yield among experiments has been shown. The treatment effect was due to N, P and/or K. Multiple regression analysis was applied to the yields obtained from each replicate to ascertain these effects.

The regression statistics obtained from fitting the yield equation,

$$Y = B_0 + B_1N + B_2P + B_3K + B_4N^2 + B_5P^2 + B_6K^2 + B_7NP \\ + B_8NK + B_9PK,$$

to the data are shown in Table 16.

In general the effects due to applied N, P and K appear quite diverse. The reason or reasons for response or lack of response are obvious in some experiments but are not readily apparent in others. Since the ultimate goal is to relate these differences in responsiveness to specific uncontrolled factors through a combined regression analysis, no attempt will be made at this point to explain why or why not a given response did or did not occur. However, the responses that did occur will be pointed out.

Four of the six 1959 experiments responded to applied N and in all cases the response decreased at higher rates of N. A decrease in yield due to high rates of N was indicated by the significant negative quadratic coefficient for N in Replicate 1 of Experiment 2. A response to P was obtained in

Table 16. Regression coefficients and R^2 -values obtained from fitting a second degree polynomial with interactions to the corn yield data from each replicate of each experiment

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|-----------------------|-----------------------|-----------------------|
| | | 1 | 2 | 3 |
| 1 | b_0 | 72.1746 | 82.5840 | 76.9107 |
| | b_1 | 0.3088** | 0.2986 | 0.3460** |
| | b_2 | -0.1578 | 0.1103 ⁺ | 0.1258 |
| | b_3 | -0.0874 ⁺ | 0.3942 ⁺ | 0.1752 |
| | b_4 | -0.0014 ⁺ | -0.0013 ⁺⁺ | -0.0015 ⁺⁺ |
| | b_5 | -0.0065 ⁺ | 0.0052 ⁺ | -0.0050 |
| | b_6 | 0.0033 | -0.0029 | -0.0017 |
| | b_7 | 0.0055* | -0.0034* | 0.0021 |
| | b_8 | -0.0008 | 0.0003 | 0.0002 |
| | b_9 | 0.0042 | -0.0019 | 0.0018 |
| | R^2 | 0.805 | 0.785 | 0.785 |
| 2 | b_0 | 74.4047 | 80.1981 | 71.5693 |
| | b_1 | 0.2554* | -0.0044 | 0.6915** |
| | b_2 | 0.2103 | 0.3146* | -0.2662 |
| | b_3 | 0.1748 ⁺ | -0.2186* | -0.3005 |
| | b_4 | -0.0010 ⁺ | -0.0003 | -0.0029* |
| | b_5 | -0.0091 ⁺⁺ | 0.0012 | -0.0025 |
| | b_6 | 0.0147 | 0.0060 ⁺ | 0.0016 |
| | b_7 | 0.0044* | 0.0006 | 0.0009 |
| | b_8 | -0.0027 ⁺ | 0.0012 | 0.0005 |
| | b_9 | 0.0019 | -0.0022 | 0.0032 |
| | R^2 | 0.0756 | 0.729 | 0.739 |
| 1 | | 4 | 5 | 6 |
| | b_0 | 66.7044 | 97.6347 | 102.2914 |
| | b_1 | 0.2287 | 0.1621* | 0.1825* |
| | b_2 | 0.1095 | 0.0105 ⁺ | -0.1423 |
| | b_3 | 0.3952 ⁺ | 0.1220 | 0.0405 |
| | b_4 | -0.0004 | -0.0008 ⁺ | -0.0010 ⁺ |
| | b_5 | -0.0012 | 0.0000 | 0.0008 |

Table 16. (Continued)

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|-----------------------|-----------------------|----------------------|
| | | 4 | 5 | 6 |
| 1 | b_6 | -0.0008 | -0.0007 | -0.0004 |
| | b_7 | -0.0014 | 0.0017 ⁺ | 0.0015 |
| | b_8 | -0.0012 | 0.0001 | 0.0003 |
| | b_9 | 0.0003 | -0.0019 | 0.0000 |
| | R^2 | 0.553 | 0.797 | 0.634 |
| 2 | b_0 | 71.2683 | 86.5595 | 94.7039 |
| | b_1 | 0.0720 | 0.5823** | 0.2411* |
| | b_2 | -0.3439 | -0.3448 | -0.2346 |
| | b_3 | 0.5502** | -0.1368 | 0.1891 |
| | b_4 | -0.0007 | -0.0025** | -0.0011* |
| | b_5 | 0.0036 | 0.0004 ⁺ | 0.0004 ⁺ |
| | b_6 | -0.0026 | -0.0003 | -0.0028 ⁺ |
| | b_7 | 0.0018 ⁺ | -0.0005 | -0.0004 |
| | b_8 | -0.0007 | 0.0002 | 0.0003 |
| | b_9 | -0.0015 | 0.0043 ⁺ | -0.0001 |
| | R^2 | 0.641 | 0.917 | 0.738 |
| | | 1960 Experiment | | |
| | | 1 | 2 | 3 |
| 1 | b_0 | 73.8742 | 62.4897 | 76.7573 |
| | b_1 | 0.2855 | 0.1773 | 0.5243** |
| | b_2 | 0.5228 | 0.4098 ⁺⁺ | -0.9145 ⁺ |
| | b_3 | 0.0640 ⁺ | 0.4812 | 0.3243 ⁺ |
| | b_4 | -0.0011 | -0.0003 | -0.0026** |
| | b_5 | -0.0058 | -0.0027 | 0.0052 ⁺ |
| | b_6 | 0.0003 | -0.0021 | -0.0026 |
| | b_7 | 0.0005 | -0.0003 | -0.0007 |
| | b_8 | -0.0019 ⁺⁺ | -0.0022 ⁺⁺ | 0.0006 |
| | b_9 | -0.0040 | -0.0007 | -0.0024 ⁺ |
| | R^2 | 0.414 | 0.328 | 0.723 |
| 2 | b_0 | 84.3516 | 70.9530 | 88.4657 |
| | b_1 | 0.1929 ⁺⁺ | 0.2517** | 0.4948** |
| | b_2 | 0.5199 | 0.8113** | 0.8009 |
| | b_3 | -0.6413 | -0.4085 | -0.2254 |
| | b_4 | -0.0008 | -0.0006 | -0.0031* |

Table 16. (Continued)

| Replicate | Regression coefficient | 1960 Experiment | | |
|-----------|------------------------|-----------------------|----------------------|----------------------|
| | | 1 | 2 | 3 |
| 2 | b ₅ | -0.0088 ⁺⁺ | -0.0083* | -0.0008 |
| | b ₆ | 0.0070 ⁺ | 0.0054* | 0.0003 |
| | b ₇ | 0.0002 | -0.0011 ⁺ | -0.0007 |
| | b ₈ | -0.0003 | -0.0010 ⁺ | 0.0027* |
| | b ₉ | 0.0036 ⁺⁺ | 0.0003 | 0.0010 |
| | R ² | 0.551 | 0.780 | 0.689 |
| | | 4 | 5 | 6 |
| 1 | b ₀ | 61.1081 | 63.5163 | 71.5778 |
| | b ₁ | 0.5609** | 0.3043** | 0.0731** |
| | b ₂ | 0.4282* | 0.5710 | 0.0918** |
| | b ₃ | -0.0031 ⁺ | -0.0004 | -0.1552 |
| | b ₄ | -0.0026** | -0.0003 | 0.0004 |
| | b ₅ | -0.0060 ⁺ | -0.0084 ⁺ | 0.0007 |
| | b ₆ | 0.0040 ⁺ | 0.0008 | 0.0006 |
| | b ₇ | 0.0019 ⁺⁺ | -0.0001 | 0.0004 |
| | b ₈ | 0.0005 | 0.0006 | 0.0007 |
| | b ₉ | 0.0005 | 0.0008 | 0.0017 |
| | R ² | 0.865 | 0.776 | 0.739 |
| 2 | b ₀ | 68.5061 | 72.3070 | 76.7278 |
| | b ₁ | 0.2156** | 0.8225** | 0.1848** |
| | b ₂ | 0.7561** | -0.1308** | 0.3554 |
| | b ₃ | -0.0007 ⁺⁺ | -0.0049 | -0.1896 |
| | b ₄ | -0.0006 | -0.0041** | -0.0003 |
| | b ₅ | -0.0094* | 0.0042 ⁺ | -0.0086 ⁺ |
| | b ₆ | 0.0003 ⁺ | 0.0013 | 0.0024 |
| | b ₇ | 0.0015 | 0.0000 | 0.0037* |
| | b ₈ | -0.0006 | 0.0007 | 0.0004 |
| | b ₉ | 0.0005 | 0.0011 | -0.0002 |
| | R ² | 0.822 | 0.904 | 0.698 |
| | | 7 | 8 | 9 |
| 1 | b ₀ | 53.5254 | 83.7770 | 91.6305 |
| | b ₁ | 0.3175 | 0.2964 ⁺⁺ | -0.0222 |
| | b ₂ | -0.2244 | -0.1040 | -0.0348 ⁺ |
| | b ₃ | 0.3492 | 0.1437* | -0.2423 ⁺ |

Table 16. (Continued)

| Replicate | Regression coefficient | 1960 Experiment | | |
|-----------|------------------------|----------------------|----------------------|----------------------|
| | | 7 | 8 | 9 |
| 1 | b ₄ | -0.0015 | -0.0023* | -0.0001 |
| | b ₅ | -0.0023 | -0.0034 | 0.0053 |
| | b ₆ | -0.0036 | -0.0007 | 0.0006 |
| | b ₇ | 0.0006 | 0.0017 ⁺ | -0.0005 |
| | b ₈ | -0.0000 | 0.0017 ⁺ | 0.0017** |
| | b ₉ | -0.0006 | -0.0013 | 0.0002 |
| | R ² | 0.563 | 0.624 | 0.588 |
| 2 | b ₀ | 58.3023 | 77.3135 | 91.8419 |
| | b ₁ | 0.0858 ⁺ | 0.0640 ⁺⁺ | -0.0799 |
| | b ₂ | 0.3197 ⁺⁺ | -0.2951 | 0.0125 ⁺⁺ |
| | b ₃ | 0.3492* | 0.8768** | -0.0737 |
| | b ₄ | -0.0006 ⁺ | -0.0004 | 0.0001 |
| | b ₅ | -0.0063 ⁺ | -0.0032 | -0.0027 |
| | b ₆ | -0.0029 ⁺ | -0.0080* | -0.0001 |
| | b ₇ | 0.0007 ⁺ | 0.0024* | 0.0011 ⁺ |
| | b ₈ | 0.0001 | -0.0005 | 0.0008 ⁺ |
| | b ₉ | -0.0013 ⁺ | 0.0008 | -0.0007 |
| | R ² | 0.744 | 0.733 | 0.431 |
| 1 | | 10 | 11 | 12 |
| | b ₀ | 110.6214 | 82.8632 | 42.7439 |
| | b ₁ | 0.0499* | 0.1508* | 0.2853** |
| | b ₂ | 0.3390 | 0.2680 ⁺ | -0.3152 |
| | b ₃ | 0.1514 | -0.0981 | 0.3676** |
| | b ₄ | 0.0003 | -0.0006 | -0.0001* |
| | b ₅ | 0.0035 | -0.0002 | 0.0000 |
| | b ₆ | -0.0010 | 0.0009 | -0.0016 ⁺ |
| | b ₇ | -0.0006 | 0.0001 | 0.0011* |
| | b ₈ | 0.0000 | 0.0001 | 0.0007* |
| | b ₉ | -0.0019 ⁺ | -0.0003 ⁺ | -0.0019 |
| | R ² | 0.501 | 0.577 | 0.911 |

Table 16. (Continued)

| Replicate | Regression coefficient | 1960 Experiment | | |
|-----------|------------------------|-----------------------|----------------------|---------------------|
| | | 10 | 11 | 12 |
| 2 | b_0 | 93.9756 | 81.6213 | 57.7913 |
| | b_1 | 0.2959** | 0.2728** | 0.2575** |
| | b_2 | 0.7351* | 0.1121 ⁺⁺ | 0.0316 |
| | b_3 | -0.0615 | -0.0220 | -0.1928** |
| | b_4 | -0.0008 ⁺ | -0.0012 ⁺ | -0.0013* |
| | b_5 | -0.0036 ⁺⁺ | 0.0019 | 0.0002 |
| | b_6 | 0.0002 | 0.0008 | 0.0026 ⁺ |
| | b_7 | -0.0013 ⁺⁺ | 0.0016 ⁺ | 0.0018* |
| | b_8 | 0.0008 ⁺ | 0.0003 | 0.0012* |
| | b_9 | -0.0013 | -0.0034 ⁺ | 0.0012 |
| | R^2 | 0.855 | 0.760 | 0.899 |

Experiment 2 and Replicate 1 of Experiment 5. The response to P was linear in Replicate 2 of Experiment 2 and Replicate 1 of Experiment 5. An increasing response at higher rates of P was obtained in Replicate 1 of Experiment 2. An increase in yield at high rates of P is indicated by the positive quadratic coefficients for P in Replicate 2 of Experiment 5 and Replicate 2 of Experiment 6. The response to K in 1959 was erratic. A positive linear response was obtained in Replicate 2 of Experiment 2 and in Experiment 4. The response to K was negative in Replicate 1 of Experiment 1 but was positive in Replicate 2. In Replicate 2 of Experiment 2 the response to K was negative at lower rates of K but was positive at higher rates.

The twelve 1960 experiments gave results that were as diverse as those obtained in 1959. The linear N coefficient

attained some degree of significance in 1960 Experiments 3, 4, 5, 6, 8, 10, 11 and 12 and in the second replicate of Experiments 1, 2 and 7. The N effect was positive in all cases but in some cases decreasing returns at higher rates of N was indicated by a significant negative quadratic term for N. The total lack of N effect in Experiment 9 may be attributed to the high incidence of stress days.

Positive linear P coefficients in Experiments 2, 4 and 11, in Replicate 1 of Experiments 6 and 10 and in Replicate 2 of Experiments 7 and 9 attained some degree of significance. Negative coefficients were obtained in Replicates 1 of Experiment 3, 2 of Experiment 5 and 1 of Experiment 9. However, in Replicates 2 of Experiment 5 and 1 of Experiment 3 the P effect was positive at higher rates of P as indicated by the positive quadratic P coefficient. Where responses to P occurred at all rates of P, the effect was linear only except in Experiment 4 and Replicates 2 of Experiment 2 and 2 of Experiment 7. Decreasing yields at high rates of P were indicated by a non-significant linear term and significant negative quadratic coefficient in Replicates 1 of Experiment 2, 1 of Experiment 5, 2 of Experiment 6 and 2 of Experiment 10.

A positive linear response to K was obtained in Replicates 1 of Experiment 1, 0 of Experiment 3, and 1 of Experiment 8. An opposite effect was indicated in Replicate 1 of Experiment 9 by the negative linear coefficient. The response to K was

curvilinear with yields decreasing at high rates of K in Replicates 2 of Experiment 7, 2 of Experiment 8, and 1 of Experiment 12. A positive response to K was obtained at higher rates of K in Experiment 4 and Replicate 2 of Experiment 12 as indicated by the positive quadratic coefficient for K and negative linear coefficient.

The effects of the significant interactions of NP, NK and PK were different in both the 1959 and 1960 experiments. A general interpretation of the interaction effects is as follows. A positive interaction in conjunction with nonsignificant or significant positive linear effects of the respective elements indicates a greater response to one or both of the elements at higher levels of the other, and a positive interaction associated with significant negative linear terms indicates a smaller negative response to one or both of the elements at higher levels of the other. If a negative interaction occurs in conjunction with significant positive linear effects, it indicates a smaller response to one or both of the elements at higher rates of the other. However, if a negative interaction is associated with significant negative effects, it indicates a further decrease in yield due to one or both of the elements at higher rates of the other.

There appears to be as much difference in the effect of applied N, P and K between replicates of one experiment as among experiments. It is these differences in treatment

effect that are of primary interest. Due to the amount of experimental data and the complex nature of these data it was impossible to explain differences in treatment effect by direct examination of the data. Therefore a method was developed for ascertaining which factors were causing these differences.

6. Effect of evaluated uncontrolled variables on yield response to applied N, P and K

The method developed to ascertain which uncontrolled variable or variables affected yield response to applied N, P and/or K utilized the estimated regression parameters from each replicate of each experiment. The major assumption made was that each regression equation adequately described the treatment effect and that the regression coefficients described the effect of the respective applied nutrients. The regression coefficients, evaluated at the origin, were related to the soil, management and weather factors by simple correlations according to the method developed in Section D, Part III.

The correlation values indicating the relationship between the regression coefficients and uncontrolled factors are presented in Table 17. Values for the soil factors and stand were on a replicate basis and therefore the r-value significance was determined at 34 degrees of freedom. Whereas, values for the planting date, yield potential and moisture

Table 17. Correlation values^a showing the relationship of the regression coefficients, obtained from fitting the yield equation $Y = B_0 + B_1N + B_2P + B_3K + B_4N^2 + B_5P^2 + B_6K^2 + B_7NP + B_8NK + B_9PK$ to each replicate, to uncontrolled factors

| Uncontrolled factor | Regression coefficient | | | | |
|---------------------|------------------------|----------------------|---------------------|----------------------|---------------------|
| | b_1 | b_2 | b_3 | b_4 | b_5 |
| N_S | -0.417* | -0.082 | 0.128 | 0.330* | -0.066 |
| P_S | -0.169 | -0.178 | -0.145 | 0.001 | -0.156 |
| K_S | -0.292 ⁺⁺ | 0.294 ⁺⁺ | -0.270 ⁺ | 0.129 | -0.262 ⁺ |
| pH | 0.098 | -0.076 | 0.119 | -0.256 ⁺ | 0.185 |
| S | -0.239 ⁺ | 0.121 | 0.228 ⁺ | 0.057 | -0.035 |
| T | -0.439 ⁺⁺ | -0.044 | 0.222 | 0.494* | 0.034 |
| Y | -0.454 ⁺⁺ | 0.058 | -0.039 | 0.083 | -0.085 |
| D_1 | -0.102 | -0.253 | 0.370 ⁺ | -0.426 ⁺⁺ | -0.112 |
| D_2 | -0.248 | 0.203 | 0.233 | -0.157 | -0.189 |
| D_3 | -0.247 | 0.229 | 0.116 | 0.259 ⁺ | -0.218 |
| | b_6 | b_7 | b_8 | b_9 | |
| N_S | -0.046 | 0.031 | -0.104 | -0.078 | |
| P_S | -0.095 | -0.260 ⁺ | 0.399* | 0.060 | |
| K_S | 0.152 | -0.043 | 0.060 | -0.111 | |
| pH | -0.074 | -0.022 | 0.067 | 0.084 | |
| S | 0.187 | -0.288 ⁺⁺ | 0.000 | 0.003 | |
| T | -0.254 | 0.126 | 0.043 | -0.213 | |
| Y | -0.248 | -0.121 | 0.260 ⁺ | -0.246 | |
| D_1 | -0.161 | 0.106 | -0.386 ⁺ | 0.215 | |
| D_2 | -0.062 | -0.116 | -0.206 | 0.011 | |
| D_3 | 0.065 | 0.004 | -0.228 | 0.171 | |

^aThe degrees of freedom were 34 for N_S , P_S , K_S , pH and S. Since the other factors were imposed on both replicates at each location, averages of the two regression coefficients were used and the degrees of freedom were 16.

stress periods were on an experiment basis and the significance of the r-value was determined at 16 degrees of freedom.

The significant relationships between the regression coefficients and the measured uncontrolled factors indicate that the values of the regression coefficients change as certain uncontrolled factors vary in value. Therefore, if the individual yields from all experimental plots are to be described as a function of applied fertilizer and uncontrolled factors, the yield function must be flexible in form in order to describe changes in response to applied fertilizer under various levels of uncontrolled factors. The effects of the relationships designated in Table 17 may be inserted into a polynomial equation as linear by linear and linear by quadratic interactions between the uncontrolled factors and applied or controlled factors, i.e., the significant relationship between soil N and the linear coefficient for applied N indicates a soil N by applied N interaction and the relationship between soil N and the second degree coefficient for applied N indicates a soil N by applied N^2 interaction.

In order to ascertain whether the suggested interactions were valid these indicated interactions were entered into a regression equation also containing the uncontrolled variates affecting check yield as given in Table 11 and the variates from the regular second degree polynomial fitted to the individual replicate yields. A total of 46 variates was

considered in the regression equation fitted to the 780 individual plot observations. Variates were eliminated from this final yield equation on the basis of a nonsignificant simple r -value relating the particular variate to total yield or on the basis of a nonsignificant t -value for the regression coefficient of the variate in the final yield equation. The variates which were deleted on the basis of the simple r -value were $P_S \times NP$, $K_S \times K$, $K_S \times P^2$, $y \times NK$ and $D_1 \times NK$. The variates which were deleted on the basis of the t -value were K^2 , PK , $y \times N_S$, $y \times P_S$, $D_1 \times D_2$, $K_S \times P$, $T \times N$, $D_3 \times N^2$, $S \times N$, $S \times K$ and $D_1 \times K$. The amount of the total variation accounted for by the variates deleted on the basis of the t -value was nonsignificant according to a F -test.

The final equation which was considered to be adequate is shown in Table 18 with appropriate regression statistics. The coefficients of the applied variates were decoded, evaluated at zero input levels of the uncontrolled factors and transformed into bushels per acre per pound of input. This equation was highly significant at the 0.01 level of probability and attained an R^2 -value of 0.599, i.e., approximately 60 percent of the plot variation was accounted for by this equation. The coefficients of the N^2 and NK variates were nonsignificant but these terms were retained in the equation because they were included in interaction terms.

The interaction terms involving uncontrolled and controlled factors from this yield equation containing 30

Table 18. Regression of all plot corn yields on observed and fertilizer variates and the correlation values of corn yield with each variate

| Variate | Equation $\hat{Y} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{Yx_i \cdot x_j}^a$ |
|---------------------|--|--|------------------------|
| | -157.21689 ^b | | |
| N | +0.12687 x_1 | ** | 0.368** |
| P | -0.02472 x_2 | ** | 0.086* |
| K | +0.06036 x_3 | * | 0.068 ⁺ |
| N ² | +0.00101 x_4 | | -0.221** |
| P ² | -0.00190 x_5 | * | -0.158** |
| NP | +0.00259 x_6 | ++ | 0.045 ⁺ |
| NK | -0.00031 x_7 | | 0.009 |
| S | +20.74477 x_8 | ** | 0.438** |
| S ² | -0.60962 x_9 | ** | 0.406** |
| N _S | +0.31303 x_{10} | + | 0.161** |
| P _S | -5.51330 x_{11} | * | 0.179** |
| K _S | +0.05811 x_{12} | ** | 0.192** |
| pH | -0.10750 x_{13} | * | 0.262** |
| P _S x pH | +0.82468 x_{14} | * | 0.193** |
| W | +5.71988 x_{15} | * | 0.423** |
| T | -0.04819 x_{16} | ** | -0.193** |
| Y | +3.93037 x_{17} | ** | 0.094* |

^a $i, j = 1 \dots 30. \quad i \neq j.$

^bThis is b_0 , the constant in the regression equation.

Table 18. (Continued)

| Variate | $\hat{Y} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{Yx_i \cdot x_j}^a$ |
|---------------------------------|--------------------------------|--|------------------------|
| D ₁ | +0.17427 X ₁₈ | * | -0.125** |
| D ₂ | +1.31355 X ₁₉ | ++ | -0.263** |
| D ₃ | -0.25732 X ₂₀ | ++ | -0.129** |
| D ₂ x D ₃ | -0.07495 X ₂₁ | ++ | -0.229** |
| N _S x N | -0.00246 X ₂₂ | ** | 0.344** |
| N _S x N ² | +0.00003 X ₂₃ | * | -0.176** |
| P _S x NK | +0.00008 X ₂₄ | ++ | 0.044 ⁺ |
| K _S x N | +0.00027 X ₂₅ | * | 0.348** |
| T x N ² | +0.00003 X ₂₆ | ++ | -0.243** |
| S x NP | -0.00015 X ₂₇ | + | 0.038 ⁺ |
| Y x N | -0.01207 X ₂₈ | ++ | 0.360** |
| D ₁ x N ² | -0.00003 X ₂₉ | + | -0.196** |
| pH x N ² | -0.00073 X ₃₀ | * | -0.198** |

variates show that the major effect of the uncontrolled factors was on applied N. Applied P and K were affected only as to their interaction with N. This may be a consequence of the consistent response to N and inconsistent response to P and K as shown by the replicate regression equations in Table 16.

As this regression equation was obtained from all plot yields, it will be interpreted with respect to how the effects of applied plant nutrients varied as the uncontrolled factors

varied in value. Soil N appeared to substitute for fertilizer N as shown by the negative $N_s \times N$ interaction. The positive $N_s \times N^2$ interaction shows that the rate of decrease of the response to rates of fertilizer N lessens as soil N increases. This effect is shown in Figure 2A where the rate of change of yield is plotted against rates of applied N. Low soil N is 46 pounds and high soil N is 109 pounds per acre. All other factors, controlled and uncontrolled, were held at average experimental values. Any point on the respective lines is a solution of the following first partial derivative of yield with respect to applied N:

$$\begin{aligned} \frac{\partial Y}{\partial N} = & b_1 + 2b_4N + b_6P - b_7K - b_{22}N_s + 2b_{23}N_sN + b_{24}P_sK + b_{25}K_s \\ & + 2b_{26}TN - b_{27}SP - b_{28}Y - 2b_{29}D_1N - 2b_{30}PHN. \end{aligned}$$

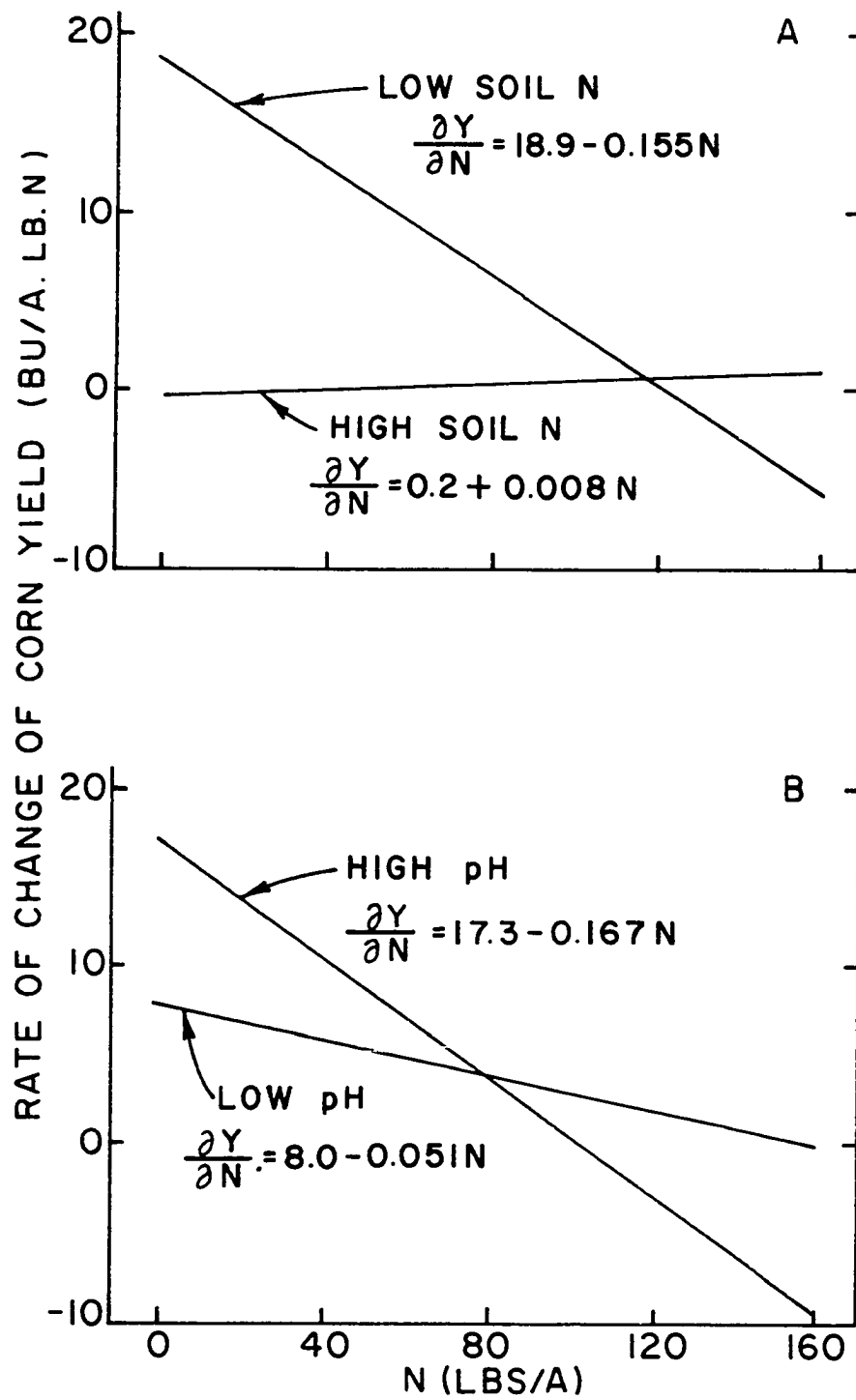
By substituting in the appropriate values the partial derivative reduces to the form of

$$\frac{\partial Y}{\partial N} = a + cN$$

for each line in Figure 2A. The constant, a , will vary as determined by interactions with applied N. The slope, c , of the line will vary as determined by linear x quadratic interactions with the quadratic term for applied N.

Some general characteristics of this type of diagram may be noted. The initial starting point of a rate of change line is the initial slope at zero pounds of input. Any point on the rate of change line is the slope of the yield surface at

Figure 2. Rate of change of corn yield with respect to applied N at two levels of soil N and soil pH with all other factors at their average values



that particular level of input. The slope of this line indicates increasing or decreasing returns to the input factor depending on whether the slope is positive or negative. Relative slopes of two lines show whether the kind of returns differ with respect to the factor, other than the input factor, considered. If a rate of change line with a negative slope crosses zero, this shows the point of maximum yield attained with respect to the input factor at the specific levels of the other factors.

Figure 2A which shows the rate of change of yield at two levels of soil N at different rates of applied N demonstrates that the initial response to applied N is greater at low levels of soil N and the response at low levels of soil N decreases at a greater rate than that at high levels of soil N. A point of maximum yield was attained at the low soil N level. The change in yield for high soil N was in a positive direction but was not significantly different from zero.

The effect of soil P on the response to applied N was manifested only in its effect on the NK interaction. As soil P increased, the interaction of applied N and K became greater. It is also of interest to note that the effect of soil P alone on yield was governed by soil pH. An increase in yield due to soil P was obtained at pH values above 6.72.

The effect of soil K on the response to applied N was shown by its positive interaction with applied N. The

response to applied N increased as soil K increased.

The effect of pH on the response to applied N is indicated by the negative pH x N² interaction shown in Table 18. This effect is displayed in Figure 2B for a low soil pH of 6.10 and high pH of 8.10 with all other factors being held at their average experimental values. The initial response to N at a high pH value is greater than at a low value. However, the response to N decreases at a more rapid rate at the high pH value and the response is zero or the maximum yield is reached at approximately 104 pounds of N per acre with the other factors being held at their average values. The response to N at the low pH value reached a maximum at 160 pounds of N.

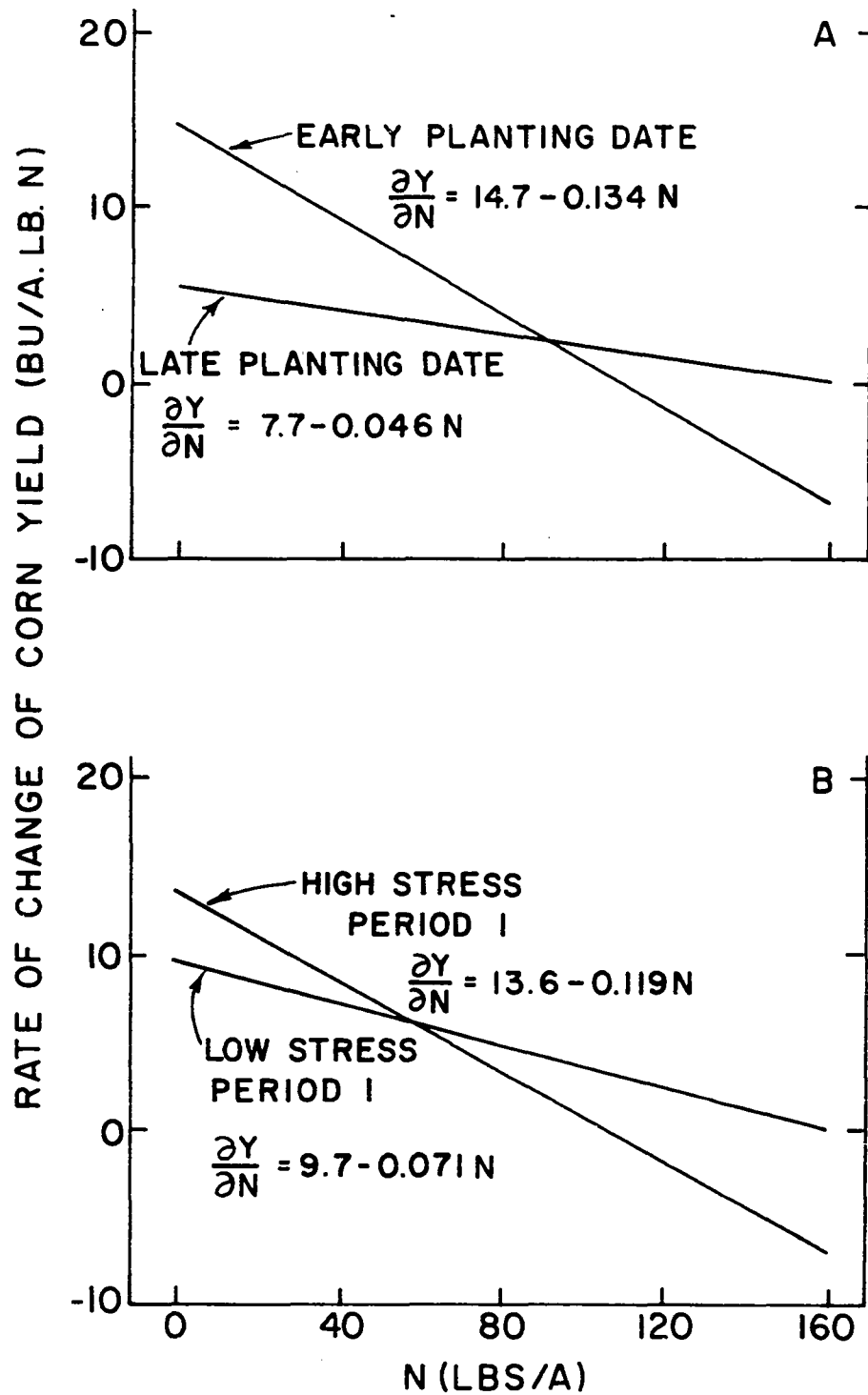
The effect of stand on the response to applied N and P is shown in Table 18 by the negative S x NP interaction. As stand increased the NP interaction decreased in value. Evidently the effect of the NP interaction on yield was diluted by the increasing number of plants. The yield potential of the various hybrids also affected the response to nitrogen as shown by the negative y x N interaction. This indicates that although a hybrid's yielding ability may increase total yield, this same characteristic is associated with a poorer utilization of applied N in terms of change in yield with respect to applied N.

The effect of time of planting is indicated by its interaction with the quadratic term for N as listed in Table 18 and

the effect as shown in Figure 3A. The early planting date was April 30 and the late planting date was June 7. The initial response to N is greater for the earlier planting date but decreases at a more rapid rate than for the later planting date at higher rates of applied N. A maximum yield was attained with respect to applied N at the early planting date but not at the later date. The effect of planting date, as indicated by these data, cannot be associated with yield only on the basis of determining the length of the growing season. It is associated indirectly with soil temperature and also with mineralization of soil N. All of these factors tend to govern the response to applied N.

The effect of stress days in the various periods on the response to applied N was limited to that of stress period 1. This is indicated by the interaction of stress period 1 with the quadratic term for applied N. The results of this effect are shown in Figure 3B. The high stress period had 20 stress days and the low stress period had none. The initial response to N was greater when stress days occurred in stress period 1 than when none occurred. However, the response decreased at a more rapid rate for a drier stress period 1. Also a maximum yield was attained at a lower level of applied N when stress period 1 was drier than when fewer stress days occurred. A greater initial response to applied N occurred in the first stress period when this period was dry and was probably due to

Figure 3. Rate of change of corn yield with respect to applied N at two planting dates and two levels of stress day incidence in stress period 1 with all other factors at their average values



the applied N being plowed under to about a 6 inch depth. Since most of the soil N was throughout the surface 6 inches of soil, the corn plants probably utilized more of the applied N when the surface soil was dry during this period. By considering all analyses of the data as shown in Tables 11, 17 and 18 it is indicated that a high incidence of stress days in this period limited the yield response to N. The linear coefficient for stress period 1 is negative in the check yield equation as shown in Table 11. Stress period one is negatively correlated with the curvilinear coefficient for N as shown in Table 17 and the coefficient for the interaction of stress period 1 with the quadratic term for N is negative. These statistics indicate that as more stress days occurred in period one the possible yield that could occur was lowered. Therefore as the response to applied N reached this limiting yield, the response decreased at an increasing rate. This explains the results obtained in Tables 17 and 18 with respect to stress period 1, i.e., a negative $D_1 \times N^2$ interaction occurred.

The effects of various levels of the uncontrolled factors on the yields¹ obtained from applied N, P and K are illustrated in Figures 4, 5, 6 and 7. Corn yield responded by a greater degree to applied N and P. Therefore, the level of K

¹Yields in subsequent illustrations are predicted yields. All discussion relative to yield surfaces pertains to predicted yields.

Figure 4. Predicted yield surface of corn as a function of applied N and P with soil N, P and K at low observed values, zero incidence of stress days and all other factors at their average observed values

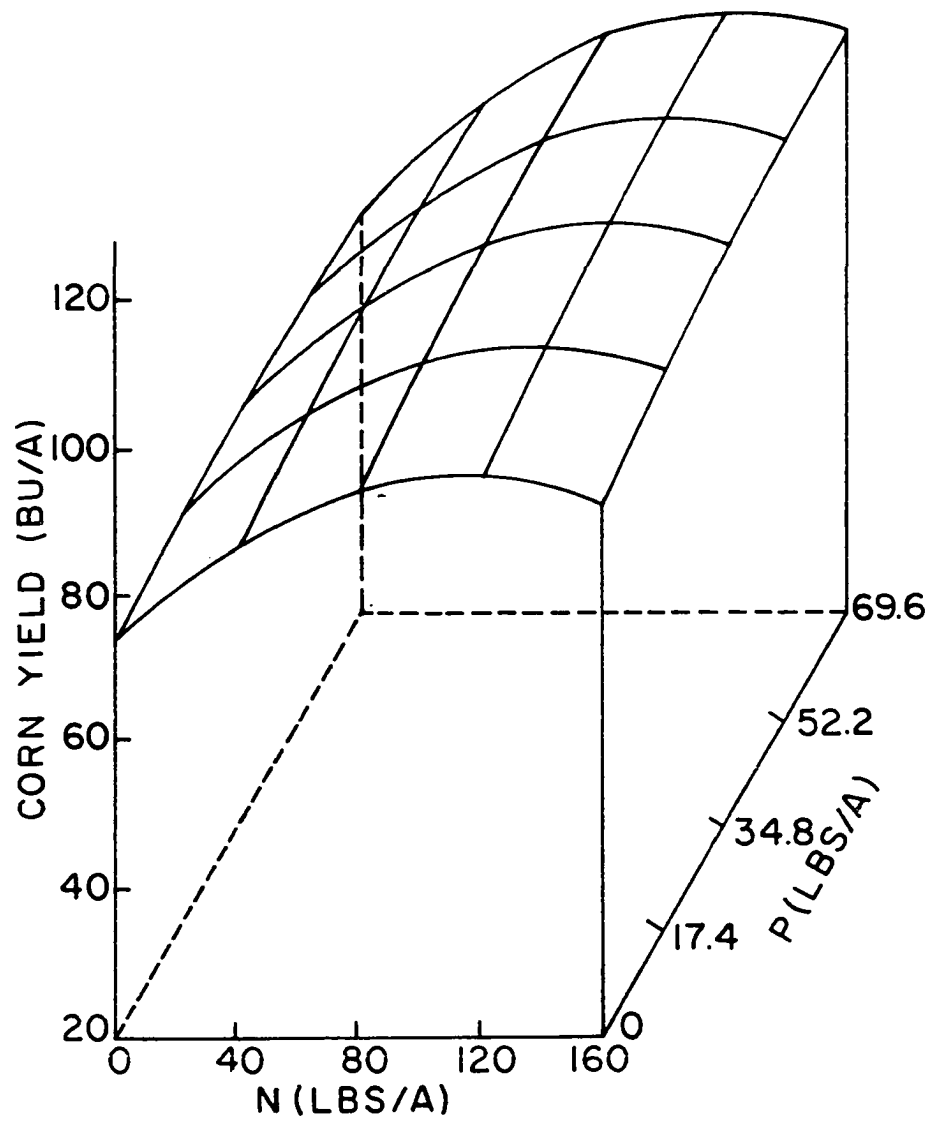


Figure 5. Predicted yield surface of corn as a function of applied N and P with soil N, P and K at low observed values, incidence of stress days at high observed values and all other factors at their average observed values

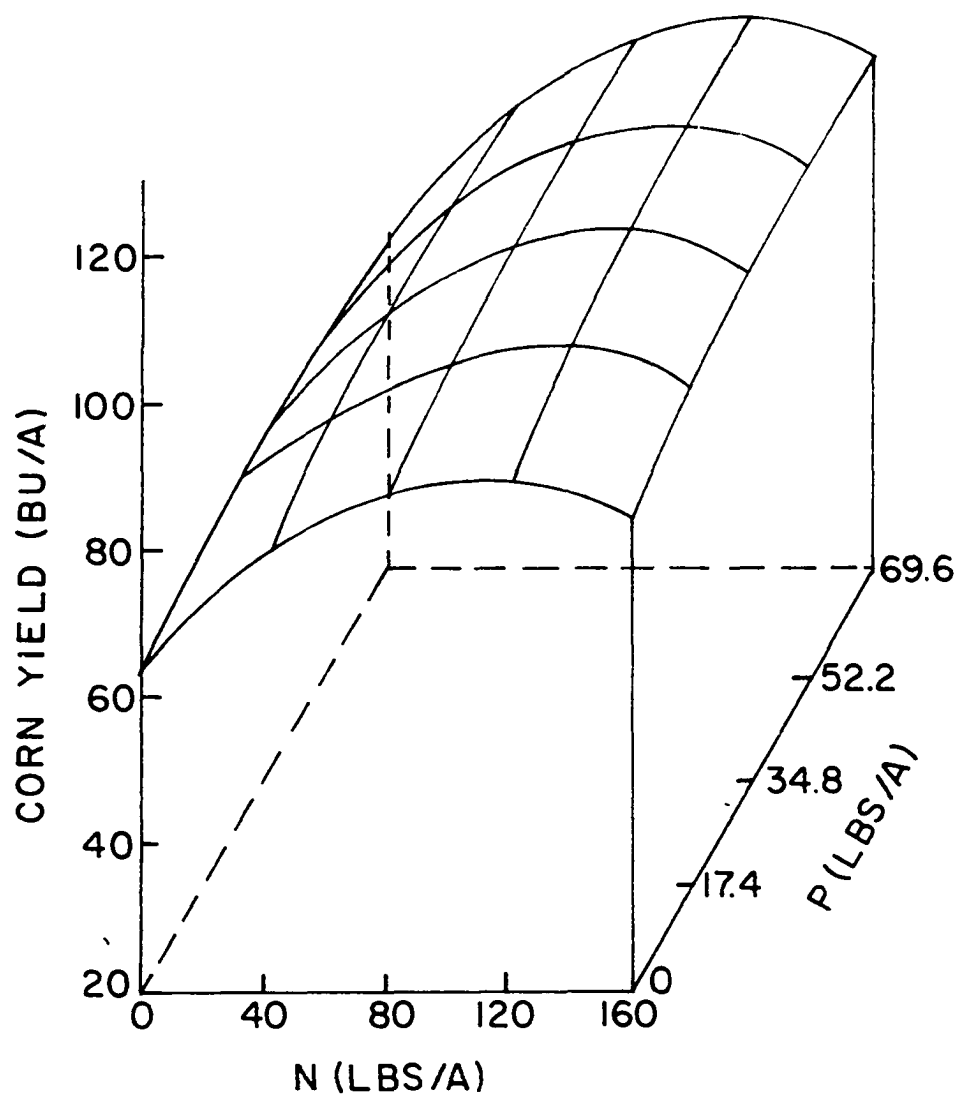


Figure 6. Predicted yield surface of corn as a function of applied N and P with soil N, P and K at high observed values, zero incidence of stress days and all other factors at their average observed values

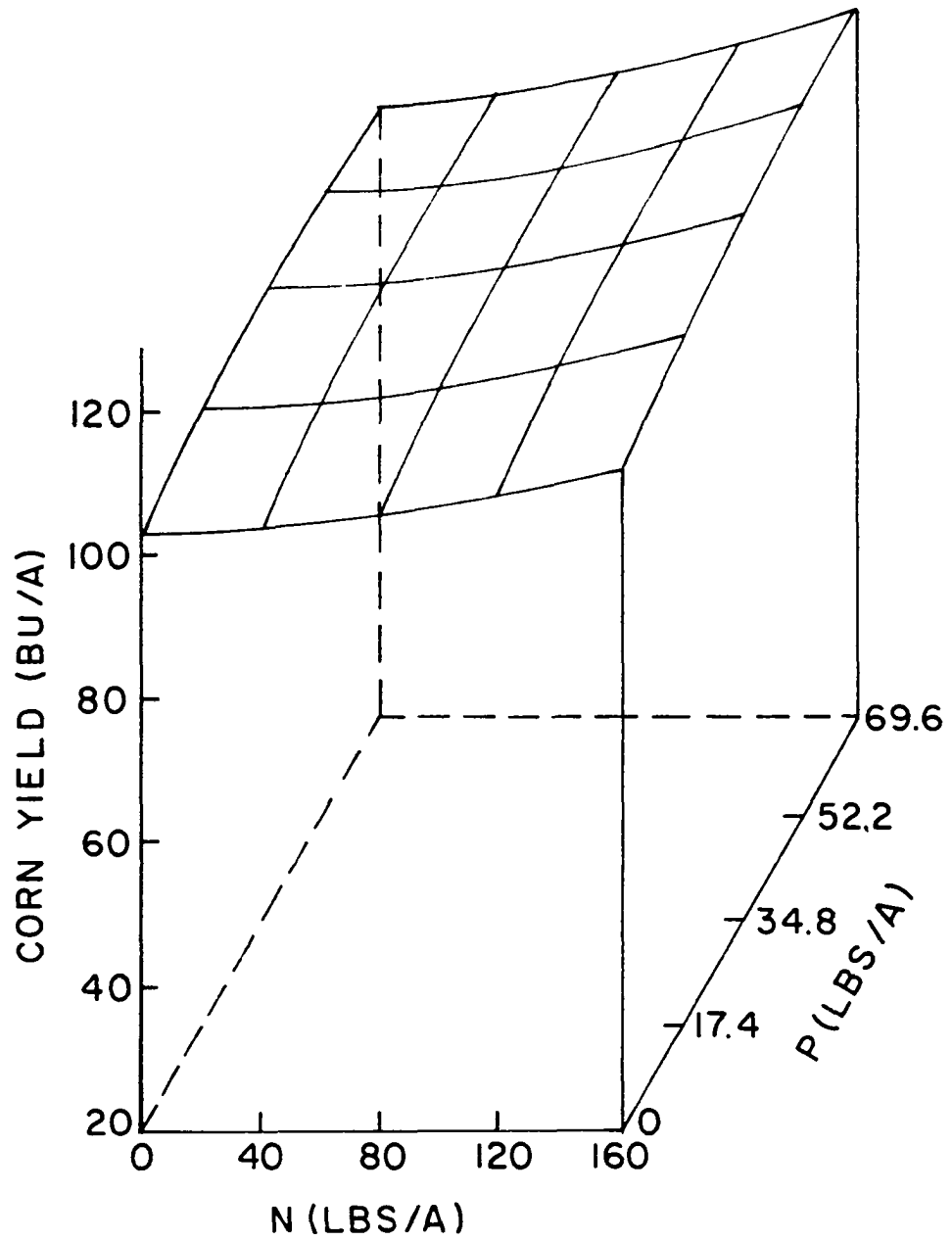
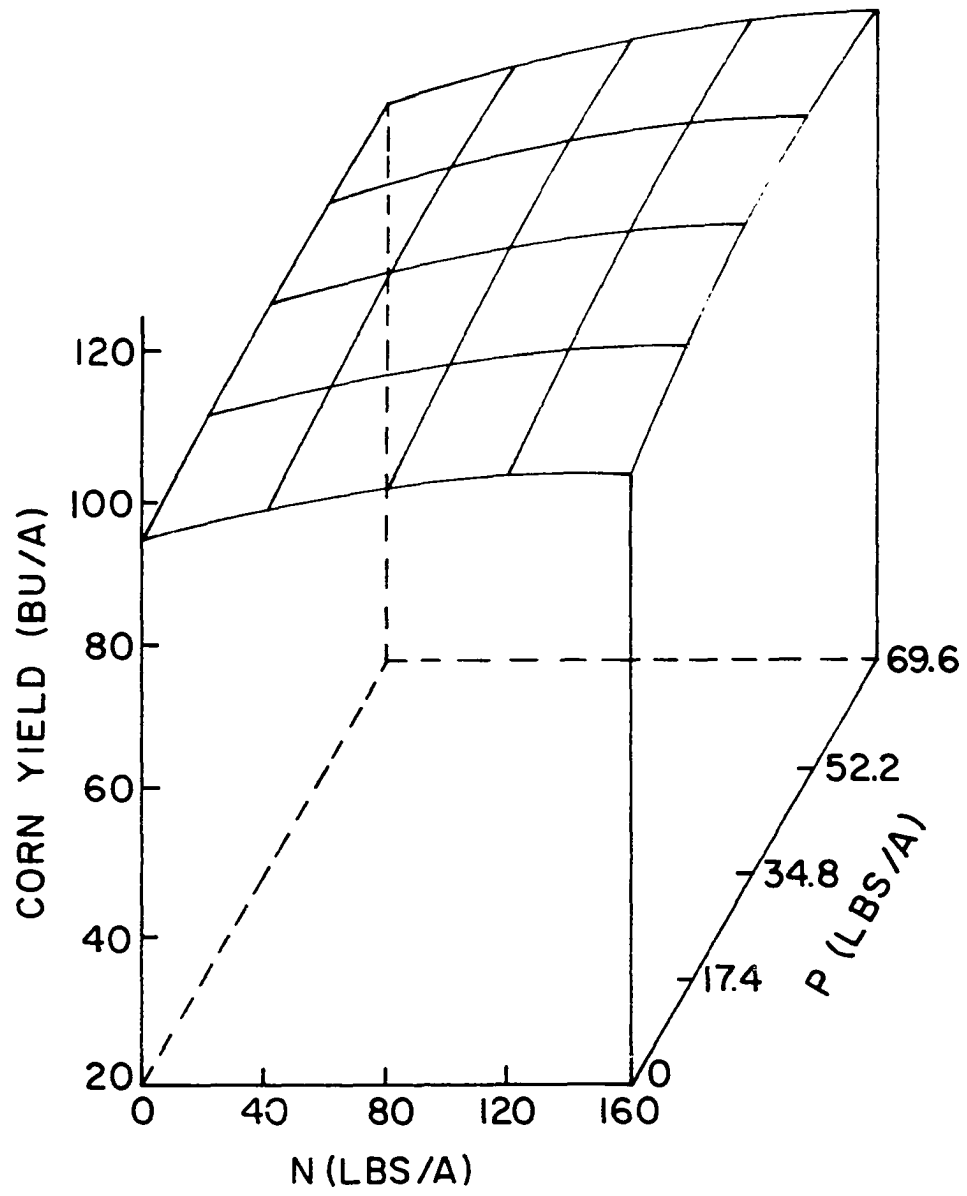


Figure 7. Predicted yield surface of corn as a function of applied N and P with soil N, P and K at high observed values, incidence of stress days at high observed values and all other factors at their average observed values



was held at a constant rate of 41.6 pounds per acre for all illustrations and N and P were allowed to vary.

Figure 4 illustrates yield as a function of applied N and P when soil N, P and K values are 46, 0.5 and 48 pounds per acre respectively. All other factors were held at their average values with the exception of the incidence of stress days in any period which was zero. The effect of P was only slightly curvilinear, whereas the effect of N was definitely curvilinear. The lowest yield, 73.2 bushels per acre, was obtained at zero input levels of N and P and the highest yield, 102 bushels per acre, was obtained at 120 pounds of N and 52.2 pounds of P.

The effect of a high incidence of stress days on yield with all other factors remaining the same as in Figure 4 is illustrated in Figure 5. The highest occurrence stress days in stress periods 1, 2 and 3 were 20, 28 and 21 respectively. The effect of applied N was more curvilinear than that obtained for the previous figure. The lowest yield, 63.8 bushels per acre was obtained at zero inputs of N and P and the highest yield, 95.3 bushels per acre, was obtained at 120 pounds of N and 52.2 pounds of P per acre.

Figure 6 illustrates yield as a function of applied N and P at high levels of soil N, P and K, which were 109, 18.4 and 320 pounds per acre, respectively in this case. All other factor values were the same as in previous figures. The most

noticeable characteristics are that total yield is high over the entire surface and that the effect of N on yield is small but in a continuous positive direction. The effect of P on yield has not changed from that in previous illustrations. The lowest yield, 103.8 bushels per acre, is at zero input levels of N and P and the highest yield, 118.6 bushels per acre, was obtained at 160 pounds of N and 52.2 pounds of P per acre.

The effect of a high incidence of drought days on yield with all factor values remaining the same as in Figure 6 is shown in Figure 7. Total yields are lower and the curvilinear effect of N is in a negative direction. The lowest yield, 94.5 bushels per acre was obtained at zero input levels of N and P and the highest yield, 109.2 bushels per acre, was obtained at 120 pounds of N and 52 pounds of P per acre.

The effect of stand, although not illustrated, was largely on total yield. As mentioned in previous discussion the interaction of applied N and P decreased as stand increased. The lower level of stand, 10.5 thousand plants as compared to an average of 14.1 thousand plants per acre, observed on an average replicate basis decreased the check yield which was obtained with high levels of soil N, P and K and zero stress day incidence by 20.5 bushels per acre. The stand necessary for maximum yield was 17.0 thousand plants per acre. This stand was obtained only in 2 replicates out of 36.

The analyses and illustrations of the data indicate that the effect of uncontrolled factors on the response to applied N, P and K may be reduced to the examination of their effect on applied N alone. Although these results may be specific to the soil type used in this experimentation, it would simplify further experimentation and analyses by considering applied P and K and uncontrolled factors as to their effect on the response of corn yield to N.

B. Concentration of N in Corn Leaves

The concentration of N in corn leaves, expressed as percent leaf N, was affected by soil, weather, fertilizer, management and the interaction of components of these factors. Factors affecting percent leaf N, other than applied fertilizer, were selected on the basis of their effect on check percent leaf N which was obtained with zero fertilizer applied. The weather characterization developed for corn yield was used. Soil factors considered were soil reaction and available levels of soil nutrients as measured by soil tests. Management factors such as corn hybrid, planting date and rate of planting were also considered. These factors were then evaluated for their effect on the response of percent leaf N to applied N, P and K. Values of these factors and methods of obtaining these values are presented in the preceding section dealing with corn yield. The factors affecting percent N in

the corn leaf, which was sampled at silking time, and the methods of selection are discussed in succeeding paragraphs.

1. Selection of soil variables

The soil variables were selected on the basis of simple correlation with check percent leaf N obtained from each replicate. The correlations of check percent leaf N with various soil test values are shown in Table 19. Check leaf N

Table 19. Simple correlation values showing the relation of check percent leaf N to surface soil test values and to selected soil test variables by depth

| Soil test variable ^a | Depth in inches | | | | |
|---------------------------------|--------------------|--------|---------------------|---------------------|---------------------|
| | 0-6 | 6-12 | 12-18 | 18-24 | 24-36 |
| Initial nitrate | 0.028 | | | | |
| Nitrifiable N(d) | 0.132 | | | | |
| Nitrifiable N(m) | 0.148 | -0.061 | -0.189 ⁺ | -0.224 ⁺ | -0.135 |
| Available P(d) | 0.204 ⁺ | 0.105 | 0.015 | 0.089 | 0.207 ⁺ |
| Exchangeable K(d) | -0.028 | | | | |
| Exchangeable K(m) | 0.225 ⁺ | 0.092 | -0.013 | -0.092 | -0.218 ⁺ |
| pH | 0.046 | | | | |

^ad and m designations refer to measurements made on air dry and field moist samples respectively.

was not related to any of the soil variables to a large degree. The subsoil contribution to check leaf N was erratic and negligible. The lack of a relation between check leaf N and nitrifiable N was due apparently to the small range in

soil N in relation to the other soil variables. The total uptake of N may have increased with increasing nitrifiable N but the concentration of N in the corn leaf was not appreciably affected.

Although check leaf N was related only to available P and exchangeable K, the nitrifiable N and soil pH were also retained for further examination to ascertain if they interacted with these and other uncontrolled factors.

2. Selection of variables other than soil

Other factors evaluated for their effect on check percent leaf N were stand (plant density), planting date, corn hybrid as characterized by yield potential, wind damage and weather as characterized by stress periods. The degree of correlation of check percent leaf N with these factors is shown in Table 20. The effect of stand on check leaf N was probably that of dilution. Check percent leaf N had a minor positive relationship with planting date indicating that either more nitrifiable N was present or that soil temperature was more conducive to the growth of the corn roots and they were then able to come into contact with more soil N. The positive relationship with the wind damage factor indicates that this adjustment accounts for a large degree of the depression of percent leaf N in the three experiments in which this damage occurred prior to silking. The effect of stress days in the different stress periods on the N concentration in the leaf varied. Check

Table 20. Simple correlation values relating check percent leaf N to stand, planting date, yield potential, wind damage factor and stress days in stress periods 1, 2, and 3

| | |
|-----------------|---------------------|
| Stand | -0.262 ⁺ |
| Planting date | 0.182 ⁺ |
| Yield potential | -0.156 |
| Wind damage | 0.337* |
| Stress period 1 | 0.004 |
| Stress period 2 | -0.512** |
| Stress period 3 | -0.491** |

percent leaf N at silking time was not affected by stress days in period 1. This lack of relationship could be due to two reasons. More of the total nitrifiable N may be available prior to and during this period than other periods and therefore the effect of dry soil would not be as critical. Also, the effect of this period could be nullified by subsequent periods. The negative relationship of check percent leaf N with stress days in periods 2 and 3 indicates that the effect was greater on the availability of soil N than on the amount of top growth.

Although yield potential and stress days in period 1 did not affect check leaf N as indicated by the correlation values, they were further examined for possible interactions with these and the soil factors.

3. Combined effect of uncontrolled variables on check percent leaf N

The purpose of the previous correlation analyses was to ascertain which variables accounted for variation in the check leaf N percentages. These variables and appropriate interactions were utilized in a multiple regression analysis to ascertain the amount of variation in check leaf N percentages accounted for by these variables. Indication of an interaction was obtained by graphical and covariance analysis as described in the previous corn yield section.

Variables which had a significance at a probability level of 0.30 as determined by a t-test for the simple or multiple relationship were retained in the multiple regression equation. The multiple regression equation variates and values of the regression coefficients are presented in Table 21. This table also shows singular relationships of check percent leaf N with the variates through simple correlation values. An R^2 -value of 0.660 was obtained for this regression equation containing 17 variates. This regression mean square was significant at the 0.10 level of probability.

This regression equation had only four terms that attained significance at some level of probability although the regression equation attained significance at 0.10. This indicates that few factors contributed to check percent leaf N in a consistent manner. The range of check leaf N was from 1.66

Table 21. Regression of check percent leaf N on observed variates, significance level of regression coefficients and correlation values and their significance obtained from relating check percent leaf N to each variate

| Variate | Equation $\hat{n} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{yx_i \cdot x_j}$ ^a |
|---------------------------------|--|--|-----------------------------------|
| | 11.67508 ^b | | |
| N _S | -0.03761 X ₁ | | 0.148 |
| P _S | -0.07561 X ₂ | | 0.204 ⁺ |
| K _S | +0.00060 X ₃ | | 0.225 ⁺ |
| P _S x K _S | +0.00003 X ₄ | | 0.269 ⁺ |
| pH | +0.05013 X ₅ | | 0.046 |
| P _S x pH | +0.00536 X ₆ | | 0.216 ⁺ |
| S | -0.81534 X ₇ | + | -0.262 ⁺ |
| S ² | +0.02688 X ₈ | + | -0.264 ⁺ |
| T | +0.01672 X ₉ | | 0.182 ⁺ |
| N _S x T | -0.00027 X ₁₀ | | 0.228 ⁺ |
| Y | -0.41001 X ₁₁ | | -0.156 |
| N _S x Y | +0.00450 X ₁₂ | | 0.250 ⁺ |
| P _S x Y | +0.00494 X ₁₃ | ++ | 0.265 ⁺ |
| W | +0.02506 X ₁₄ | | 0.337* |
| D ₂ | -0.03309 X ₁₅ | + | -0.512** |
| D ₃ | -0.00320 X ₁₆ | | -0.491** |
| D ₂ x D ₃ | +0.00085 X ₁₇ | | -0.479** |

^a_{i, j} = 1 . . . 17. i ≠ j.

^bThis is b₀, the constant in the regression equation.

to 2.96 percent. Neither the regression coefficients of soil N, soil pH and yield potential were significant at any level of probability nor were the correlations between check percent leaf N and these variates significant. However, they were retained because they interact with other factors affecting check percent leaf N.

The value of these preliminary relationships is in elucidating factors which might affect either total percent leaf N or change in percent leaf N due to applied N, P and K and not in the equation itself.

4. Effect of applied N, P and K

The presence of treatment effect on leaf N percentages from each experiment was determined by a simple analysis of variance for each experiment. The analysis of variance for each 1959 experiment is presented in Table 22 and for each 1960 experiment in Table 23.

Treatment effect attained a probability of 0.01 in 1959 Experiments 1, 3 and 6, 0.05 in Experiments 2 and 5 and 0.30 in Experiment 4. The effect of stand on percent leaf N was not evaluated by covariance in these analyses as it is to be included as an independent factor in the final multiple regression analysis. The lack of a large treatment effect in 1959 Experiment 4 was probably due to the low stand of 12,600 plants per acre. This relatively low stand did not put a stress on the soil N or applied N.

Table 22. Analysis of variance of percent leaf N for each of six experiments conducted in 1959

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|---------------------|---------------------|
| | | 1 | 2 | 3 |
| Total | 37 | | | |
| Replicates | 1 | 0.0002 | 0.0274 ⁺ | 0.2936** |
| Treatments | 18 | 0.1289** | 0.0290* | 0.1554** |
| Error | 18 | 0.0079 | 0.0111 | 0.0209 |
| | | 4 | 5 | 6 |
| Total | 37 | | | |
| Replicates | 1 | 0.0112 | 0.0000 | 0.0218 ⁺ |
| Treatments | 18 | 0.0210 ⁺ | 0.0730* | 0.0563** |
| Error | 18 | 0.0120 | 0.0286 | 0.0088 |

Differences between replicates in 1959 experiments 2, 3 and 6 are noted also. A difference of 30 and 18 pounds per acre of nitrifiable N occurred between replicates in Experiments 2 and 6 respectively. Although this is the apparent reason for these experiments, there was no appreciable difference in Experiment 3.

The treatment effect attained a probability level of 0.01 in 1960 Experiments 1, 2, 3, 4, 5, 7, 8, 10, 11 and 12, 0.05 in Experiment 9, but Experiment 6 did not show any significant differences among treatments. There is no apparent reason for the lack of differences due to treatment effect in 1960 Experiment 6.

Table 23. Analysis of variance of percent leaf N for each of twelve experiments conducted in 1960

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|---------------------|---------------------|
| | | 1 | 2 | 3 |
| Total | 45 | | | |
| Replicates | 1 | 0.0720* | 0.0362 ⁺ | 0.0095 |
| Treatments | 22 | 0.0573** | 0.0711** | 0.1874** |
| Error | 22 | 0.0096 | 0.0124 | 0.0139 |
| | | 4 | 5 | 6 |
| Total | 45 | | | |
| Replicates | 1 | 0.1150 ⁺⁺ | 0.0432 ⁺ | 0.0044 |
| Treatments | 22 | 0.1561** | 0.2419** | 0.0553 |
| Error | 22 | 0.0337 | 0.0215 | 0.0434 |
| | | 7 | 8 | 9 |
| Total | 45 | | | |
| Replicates | 1 | 0.0226 ⁺ | 0.0196 | 0.0245 ⁺ |
| Treatments | 22 | 0.0665** | 0.0696** | 0.0330* |
| Error | 22 | 0.0128 | 0.0192 | 0.0141 |
| | | 10 | 11 | 12 |
| Total | 45 | | | |
| Replicates | 1 | 0.0110 ⁺ | 0.0078 | 0.4700** |
| Treatments | 22 | 0.0272** | 0.1403** | 0.3001** |
| Error | 22 | 0.0069 | 0.0200 | 0.0274 |

Replicate differences were indicated in 1960 Experiments 1, 2, 4, 5, 7, 10 and 12. Differences in initial soil nutrients cannot be given as a reason for all replicate differences as the range in difference in nitrifiable N between replicates was from zero to 19 pounds per acre. Other soil factors and topography may have caused these differences as well as stand density.

The preceding analyses indicated different effects of treatments among experiments. A combined analysis of variance for the 1959 experiments shown in Table 24 further substantiates this inference for that year. The leaf N percentage differed among experiments as shown by the 0.01 probability level for experiments. There were consistent differences among treatments as shown by the significance of the treatments' mean square at the 0.01 probability level. The pooled errors from the individual analyses were heterogeneous for 1959, and this leaves the actual probability level for the significance of the treatment by experiments source of variation in doubt. By assuming the highest tabulated F-value for this comparison at a single experiment's degrees of freedom of 18 and 18 it attains a probability of 0.25. If the pooled errors were homogenous, the probability level would be 0.01. Therefore the true probability level for treatments by experiments is between 0.01 and 0.25. This source of variation indicates variation in the responsiveness to treatments

Table 24. Combined analysis of variance of percent leaf N for 1959 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|---------------------|
| Total | 227 | |
| Experiments | 5 | 2.2131** |
| Treatments/Experiments | 108 | 0.0773 |
| Treatments | 18 | 0.3402** |
| Treatments x Experiments | 90 | 0.0247 ^a |
| Replicates/Experiments | 6 | 0.0590 |
| Replicates | 1 | 0.0376 |
| Replicates x Experiments | 5 | 0.0633 |
| Error | 108 | 0.0149 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for this variance comparison cannot be ascertained. At 18 and 18 degrees of freedom it attained a significance level of 0.25.

among experiments.

The combined analysis of variance for the 1960 experiments appears in Table 25. These results are similar to those obtained in 1959 and the same conclusions indicated. Again, the pooled errors are heterogenous. By assuming the highest tabulated F-value for this comparison at a single experiment's degrees of freedom of 22 and 22 the treatments by experiments interaction is significant at a probability of 0.05. Therefore the true probability level for the treatments x experi-

Table 25. Combined analysis of variance of percent leaf N for 1960 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|---------------------|
| Total | 551 | |
| Experiments | 11 | 1.6807** |
| Treatments/Experiments | 264 | 0.1172 |
| Treatments | 22 | 0.9563** |
| Treatments x Experiments | 242 | 0.0409 ^a |
| Replicates/Experiments | 12 | 0.0696 |
| Replicates | 1 | 0.2643 |
| Replicates x Experiments | 11 | 0.0520 |
| Error | 264 | 0.0196 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for this variance comparison cannot be ascertained. At 22 and 22 degrees of freedom it attains a significance level of 0.05.

ments source of variation is between 0.01 and 0.05.

Considerable evidence indicating response to treatments, difference in the response among experiments and difference in percent leaf N among experiments has been shown. The treatment effect was due mainly to N but P and K also had an effect. Multiple regression analysis was applied to the values of percent leaf N, n, obtained from each replicate to ascertain these effects.

The regression statistics obtained from fitting the

equation, $n = B_0 + B_1N + B_2P + B_3K + B_4N^2 + B_5P^2 + B_6K^2 + B_7NP + B_8NK + B_9PK$, to the data are shown in Table 26. In general the increase in concentration of N in the corn leaf was due to applied N. The effects of fertilizer P and K appear to be diverse. Since the ultimate goal is to relate differences in responsiveness to specific uncontrolled factors through a combined regression analysis, no attempt will be made at this point to explain why or why not a given response did or did not occur. However, the responses that did occur will be pointed out.

All of the replicates except Replicate 1 of Experiment 4 in 1959 responded in a positive direction to applied N. The response decreased at higher rates of N in Experiment 3 and in Replicates 1 of Experiment 1, 2 of Experiment 4, 2 of Experiment 5 and 2 of Experiment 6. The effect of N on percent leaf N in Replicate 1 of Experiment 4 was negative at all rates of N. The effect of applied P on percent leaf N was negative in Experiment 1 but this effect decreased at higher rates of P. The same effect occurred in Replicate 2 of Experiment 4. The P effect was negative in Replicate 2 of Experiment 6 but a positive linear effect on N concentration in the leaf occurred in Experiment 2 as indicated by the respective linear coefficients for applied P. The effect of applied K in the 1959 experiments on percent leaf N was negative in Replicates 2 of Experiment 2 and 2 of Experiment 3

Table 26. Regression coefficients^a and R²-values obtained from fitting a second degree polynomial with interactions to the leaf N percentage data from each replicate of each experiment

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|-----------------------|----------------------|----------------------|
| | | 1 | 2 | 3 |
| 1 | b ₀ | 2.0545 | 2.2860 | 2.3015 |
| | b ₁ | 0.0838** | 0.2319* | 0.6596** |
| | b ₂ | -0.7170** | 0.1882 ⁺ | -0.2897 |
| | b ₃ | 0.3287 | 0.0042 | -0.4719 |
| | b ₄ | -0.0027** | 0.0002 | -0.0038* |
| | b ₅ | 0.0057* | -0.0022 | 0.0052 |
| | b ₆ | -0.0018 ⁺ | 0.0031 | 0.0031 |
| | b ₇ | 0.0019 ⁺⁺ | 0.0000 | 0.0022 ⁺ |
| | b ₈ | -0.0008 | -0.0018 | 0.0040 ⁺ |
| | b ₉ | -0.0032 ⁺ | -0.0001 | -0.0077 ⁺ |
| | R ² | 0.986 | 0.712 | 0.850 |
| 2 | b ₀ | 2.1183 | 2.3258 | 2.0467 |
| | b ₁ | 0.2994** | 0.1835** | 0.9657** |
| | b ₂ | -0.0500 ⁺⁺ | 0.7997* | -0.7441 |
| | b ₃ | 0.0536* | -0.8411 ⁺ | -0.8863 ⁺ |
| | b ₄ | -0.0006 | -0.0001 | -0.0021 ⁺ |
| | b ₅ | 0.0011 | -0.0010 | 0.0035 |
| | b ₆ | -0.0004 | 0.0030 | 0.0019 |
| | b ₇ | 0.0044 ⁺ | -0.0008 | -0.0017 |
| | b ₈ | -0.0018 | 0.0031 ⁺⁺ | 0.0017 |
| | b ₉ | -0.0057 ⁺ | 0.0062 ⁺ | 0.0105 ⁺ |
| | R ² | 0.905 | 0.840 | 0.902 |
| | | 4 | 5 | 6 |
| 1 | b ₀ | 2.8024 | 2.6601 | 2.6100 |
| | b ₁ | -0.0019 ⁺ | 0.4309 ⁺⁺ | 0.4773** |
| | b ₂ | -0.3427 | -0.3046 | 0.1171 |
| | b ₃ | 0.5060 | -0.8750 ⁺ | -0.3633 |
| | b ₄ | 0.0006 | -0.0020 | -0.0011 |

^avalues of b_i x 10². i = 1 . . . 9.

Table 26. (Continued)

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|-----------------------|
| | | 4 | 5 | 6 |
| 1 | b ₅ | 0.0062 | 0.0048 | -0.0051 |
| | b ₆ | -0.0005 | 0.0025 | 0.0034 |
| | b ₇ | 0.0016 | -0.0008 | 0.0005 |
| | b ₈ | -0.0014 | 0.0041 ⁺ | -0.0011 |
| | b ₉ | -0.0063 ⁺ | 0.0025 | 0.0005 |
| | R ² | 0.567 | 0.584 | 0.775 |
| 2 | b ₀ | 3.0094 | 2.1633 | 2.7010 |
| | b ₁ | 0.4316** | 0.9673** | 0.6968** |
| | b ₂ | 1.4310 ⁺ | 0.2671 | -0.9024 ⁺⁺ |
| | b ₃ | -0.0595 | -0.0007 ⁺ | 0.2649 ⁺ |
| | b ₄ | -0.0010 ⁺ | -0.0027 ⁺⁺ | -0.0119 ⁺ |
| | b ₅ | 0.0097* | 0.0033 | 0.0019 |
| | b ₆ | -0.0042 ⁺ | -0.0008 | -0.0066 ⁺ |
| | b ₇ | 0.0004 | -0.0046 ⁺ | 0.0011 |
| | b ₈ | -0.0011 | -0.0003 | -0.0036 ⁺ |
| | b ₉ | 0.0133** | -0.0026 | 0.0088 ⁺⁺ |
| | R ² | 0.802 | 0.830 | 0.822 |
| | | 1960 Experiments | | |
| | | 1 | 2 | 3 |
| 1 | b ₀ | 2.4175 | 1.7777 | 2.2343 |
| | b ₁ | 1.8819** | 0.6472** | 1.0741** |
| | b ₂ | -0.8641 | 0.2634 | -0.5787 ⁺ |
| | b ₃ | 0.2929 | 0.9091 ⁺ | 0.3406 |
| | b ₄ | -0.0009 | -0.0020 ⁺ | -0.0416** |
| | b ₅ | 0.0118 | -0.0020 | 0.0028 |
| | b ₆ | -0.0053 ⁺ | -0.0040 | -0.0041 |
| | b ₇ | -0.0004 | -0.0003 | 0.0012 |
| | b ₈ | 0.0010 | -0.0039* | -0.0011 |
| | b ₉ | -0.0002 | -0.0031 | 0.0032 |
| | R ² | 0.524 | 0.806 | 0.886 |
| 2 | b ₀ | 2.3398 | 2.1408 | 2.3611 |
| | b ₁ | 0.8130** | 0.5049** | 1.0733** |
| | b ₂ | -0.8069 | 0.0108 | -0.5776 |
| | b ₃ | -0.2587 ⁺ | 0.0266 | -0.5689 |

Table 26. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|-----------------------|-----------------------|----------------------|
| | | 1 | 2 | 3 |
| 2 | b ₄ | -0.0030* | -0.0013 ⁺ | -0.0047* |
| | b ₅ | 0.0124* | 0.0010 | 0.0000 |
| | b ₆ | 0.0029 | 0.0012 | 0.0043 |
| | b ₇ | -0.0006 | -0.0001 | 0.0042 ⁺ |
| | b ₈ | -0.0015 ⁺ | -0.0015 ⁺ | -0.0003 |
| | b ₉ | 0.0007 | -0.0009 | 0.0029 |
| | R ² | 0.807 | 0.819 | 0.836 |
| 1 | | 4 | 5 | 6 |
| | b ₀ | 2.1576 | 1.9097 | 2.9584 |
| | b ₁ | 1.1231** | 1.1734** | -0.4284** |
| | b ₂ | -0.0473 | -0.1310 ⁺ | -0.8701 |
| | b ₃ | -0.3319 ⁺⁺ | -1.0925 | -0.4208 |
| | b ₄ | -0.0039** | -0.0033 ⁺⁺ | 0.0032* |
| | b ₅ | 0.0014 | 0.0013 | 0.0086 ⁺ |
| | b ₆ | -0.0010 | 0.0133 ⁺⁺ | -0.0006 |
| | b ₇ | 0.0006 | -0.0033 ⁺ | -0.0013 |
| | b ₈ | 0.0003 | 0.0003 | 0.0019 ⁺ |
| | b ₉ | 0.0062* | 0.0017 | 0.0068 ⁺⁺ |
| | R ² | 0.937 | 0.845 | 0.751 |
| 2 | b ₀ | 2.3236 | 2.0261 | 2.5983 |
| | b ₁ | 0.5891** | 1.5541** | -0.3638* |
| | b ₂ | -0.4675 ⁺ | -0.0371 ⁺⁺ | 0.3669 |
| | b ₃ | -0.3578 | -1.0625 ⁺ | 0.8912 |
| | b ₄ | -0.0019* | -0.0068** | 0.0035 ⁺⁺ |
| | b ₅ | 0.0011 | 0.0029 | -0.0069 |
| | b ₆ | 0.0016 | 0.0104* | -0.0069 |
| | b ₇ | 0.0020 ⁺⁺ | -0.0001 | 0.0016 |
| | b ₈ | 0.0007 | 0.0010 | -0.0015 |
| | b ₉ | 0.0031 ⁺ | 0.0004 | -0.0060 ⁺ |
| | R ² | 0.928 | 0.953 | 0.521 |

Table 26. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|----------------------|
| | | 7 | 8 | 9 |
| 1 | b ₀ | 1.9115 | 2.4735 | 2.3733 |
| | b ₁ | 0.3261** | 0.6389** | 0.3077** |
| | b ₂ | 0.6367 | 0.2585 | -0.1403 |
| | b ₃ | 0.3511 | -1.0361 ⁺ | -0.5326 ⁺ |
| | b ₄ | -0.0004 | -0.0033** | -0.0015 ⁺ |
| | b ₅ | -0.0092 ⁺ | -0.0033 | -0.0015 |
| | b ₆ | 0.0002 | 0.0107* | 0.0024 |
| | b ₇ | 0.0019 | 0.0014 ⁺ | 0.0013 |
| | b ₈ | -0.0018 ⁺ | 0.0026** | 0.0005 |
| | b ₉ | -0.0051 ⁺ | -0.0046 ⁺⁺ | 0.0053 |
| | R ² | 0.687 | 0.854 | 0.605 |
| 2 | b ₀ | 2.0644 | 2.482 | 2.3330 |
| | b ₁ | 0.2844** | 0.7153** | 0.2457* |
| | b ₂ | 0.1573 | -1.1296 | -0.1445 |
| | b ₃ | -0.1781 | 0.1520 | -0.1200 |
| | b ₄ | -0.0015 ⁺ | -0.0033* | -0.0013 |
| | b ₅ | -0.0047 | 0.0103 ⁺ | -0.0022 |
| | b ₆ | 0.0028 | -0.0012 | 0.0048 |
| | b ₇ | 0.0031 ⁺⁺ | 0.0029 ⁺ | 0.0028 ⁺ |
| | b ₈ | 0.0015 ⁺ | -0.0017 ⁺ | 0.0004 |
| | b ₉ | -0.0043 ⁺ | 0.0046 ⁺ | -0.0006 |
| | R ² | 0.696 | 0.706 | 0.509 |
| | | 10 | 11 | 12 |
| 1 | b ₀ | 2.7217 | 2.2711 | 2.2088 |
| | b ₁ | 0.3828** | 0.9440** | 1.0109** |
| | b ₂ | -0.2274 | 0.8094 ⁺ | -1.2674 ⁺ |
| | b ₃ | 0.2728 | -0.6961 | 0.3310 |
| | b ₄ | -0.0013 ⁺ | -0.0042* | -0.0026 ⁺ |
| | b ₅ | -0.0028 | -0.0120 ⁺ | 0.0181 ⁺ |
| | b ₆ | -0.0009 | 0.0115 ⁺⁺ | -0.0053 |
| | b ₇ | 0.0008 | 0.0014 | -0.0015 |
| | b ₈ | -0.0010 ⁺ | -0.0005 | 0.0022 |

Table 26. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|---------------------|
| | | 10 | 11 | 12 |
| 1 | b ₉ | -0.0020 | -0.0061 ⁺ | -0.0038 |
| | R ² | 0.728 | 0.738 | 0.813 |
| 2 | b ₀ | 2.8778 | 2.2871 | 2.5637 |
| | b ₁ | 0.1371** | 1.0783** | 0.6532** |
| | b ₂ | -1.0747* | -0.4991 ⁺ | -0.4133 |
| | b ₃ | 0.2447 | -0.4447 ⁺ | -0.2568 |
| | b ₄ | -0.0001 | -0.0047* | -0.0009 |
| | b ₅ | 0.0106* | 0.0065 | -0.0019 |
| | b ₆ | -0.0035 ⁺ | 0.0048 | 0.0012 |
| | b ₇ | 0.0014 ⁺ | 0.0024 ⁺ | 0.0017 ⁺ |
| | b ₈ | 0.0003 | -0.0010 | 0.0002 |
| | b ₉ | 0.0018 | -0.0072 ⁺⁺ | 0.0025 |
| | R ² | 0.833 | 0.810 | 0.928 |

and in Experiment 5. A positive effect was indicated in Replicates 2 of Experiment 1 and 2 of Experiment 6. This effect decreased at higher rates of K in Replicate 2 of Experiment 6. A negative effect at higher rates of K was indicated by the negative coefficients of the quadratic term for K in Replicates 1 of Experiment 1 and 2 of Experiment 4.

The twelve 1960 experiments gave results that were similar to those obtained in 1959 with respect to applied N but as diverse with respect to P and K. All of the linear N coefficients attained significance at a probability of 0.05 or 0.01. The N effect was positive in all experiments except Experiment 6 which showed decreasing N concentration in the

leaf at a decreasing rate as applied N increased. The other experiments exhibited increasing percent leaf N with increasing rates of applied N, but in some cases at a decreasing rate as indicated by a significant negative quadratic term for N.

The effect of P on percent leaf N was in general negative in 1960 for those replicates that had significant linear coefficients for applied P. This was indicated in Replicates 1 of Experiment 3, 2 of Experiment 4, 1 and 2 of Experiment 5 and 2 of Experiment 11. The negative effect decreased at higher rates of P in Replicates 2 of Experiment 10 and 1 of Experiment 12 as indicated by the positive quadratic coefficients for P. Applied P increased percent leaf N at a decreasing rate in Replicate 1 of Experiment 11. The significant positive quadratic coefficients for P indicate an increase in percent leaf N at higher rates of P in Replicate 1 of Experiment 1, 1 of Experiment 6 and 2 of Experiment 8. The opposite was indicated in Replicate 1 of Experiment 7 by the negative quadratic coefficient for P.

Significant negative linear coefficients for K in Replicates 2 of Experiment 1, 1 of Experiment 4, 2 of Experiment 5, 1 of Experiment 8, 1 of Experiment 9 and 2 of Experiment 11 indicates a decrease in percent leaf N due to applied K. Significant positive quadratic coefficients for Replicates 2 of Experiment 5, and 1 of Experiment 8 indicates that this

effect decreases at higher rates of K. The linear K coefficient in Replicate 1 of Experiment 2 indicates that percent leaf N increases due to applied K. The negative quadratic coefficients for K in Replicates 1 of Experiment 1 and 2 of Experiment 10 indicates decreasing percent leaf N at high rates of K and the opposite is indicated by the positive quadratic coefficients for K in Replicates 1 of Experiment 5 and 1 of Experiment 11.

The effects of the significant interactions of NP, NK and PK were different in both the 1959 and 1960 experiments. A general interpretation of the interaction effects is as follows. A positive interaction in conjunction with non-significant or significant positive linear effects of the respective elements indicates a greater response to one or both of the elements at higher levels of the other, and a positive interaction associated with significant negative linear terms indicates a smaller negative response to one or both the elements at higher levels of the other. If a negative interaction occurs in conjunction with significant positive linear effects, it indicates a smaller response to one or both of the elements at higher rates of the other. However, if a negative interaction is associated with significant negative linear effects, it indicates a further decrease in yield due to one or both of the elements at higher rates of the other.

Although the effect of applied N on percent leaf N was consistent in most experiments, the effects of P and K were diverse. However, a trend of decreasing percent leaf N due to applied P and K was indicated. The next section deals with the analysis of factors affecting changes in percent leaf N due to applied N, P and K.

5. Effect of evaluated uncontrolled variables on response of percent leaf N to applied N, P and K

The estimated regression coefficients which were shown in Table 26 were related to the soil, management, and weather factors by simple correlation according to the method developed in Section D, Part III and applied to corn yield in the preceding section of Section A. This was that each regression equation adequately described the treatment effect and that the regression coefficients described the effect of the respective applied nutrients.

The correlation values indicating the relationship between the regression coefficients and uncontrolled factors are presented in Table 27. Significant values of the soil factors and stand were determined at 34 degrees of freedom. Whereas, values for the planting date, yield potential and stress periods were on an experiment basis and the significance of the r-value was determined with 16 degrees of freedom.

The significant relationships between the regression coefficients and the uncontrolled factors indicate that the

Table 27. Simple correlation values^a showing the relationship of the regression coefficients, obtained from fitting a second degree polynomial to the leaf N percentage data from individual replicates, to selected uncontrolled factors

| Uncontrolled factor | Regression coefficient | | | | |
|---------------------|------------------------|---------------------|---------------------|----------------------|----------------------|
| | b ₁ | b ₂ | b ₃ | b ₄ | b ₅ |
| N _S | -0.234 ⁺ | 0.243 ⁺ | 0.024 | 0.240 ⁺ | -0.104 |
| P _S | -0.041 | 0.023 | 0.058 | -0.302 ⁺⁺ | -0.222 ⁺ |
| K _S | -0.393* | 0.059 | 0.264 ⁺ | 0.140 | 0.095 |
| pH | 0.091 | 0.151 | -0.236 ⁺ | 0.000 | 0.050 |
| S | 0.067 | 0.175 | 0.086 | -0.009 | -0.077 |
| T | -0.273 ⁺ | -0.024 | 0.200 | 0.464 ⁺⁺ | -0.147 |
| Y | 0.072 | 0.239 | 0.016 | -0.101 | -0.411 ⁺⁺ |
| D ₂ | -0.322 ⁺ | 0.553* | 0.289 ⁺ | 0.236 | -0.538* |
| D ₃ | -0.323 ⁺ | 0.502* | 0.051 | 0.241 | -0.427 ⁺⁺ |
| | b ₆ | b ₇ | b ₈ | b ₉ | |
| N _S | -0.108 | -0.185 ⁺ | -0.008 | 0.103 | |
| P _S | 0.063 | 0.141 | -0.221 ⁺ | 0.093 | |
| K _S | -0.188 ⁺ | -0.039 | -0.121 | 0.028 | |
| pH | 0.056 | -0.214 ⁺ | 0.281 ⁺⁺ | 0.202 ⁺ | |
| S | 0.107 | -0.127 | -0.075 | -0.018 | |
| T | -0.062 | 0.128 | -0.092 | -0.179 | |
| Y | 0.012 | 0.147 | -0.104 | -0.056 | |
| D ₂ | -0.033 | 0.107 | -0.215 | 0.002 | |
| D ₃ | 0.083 | 0.067 | 0.014 | -0.046 | |

^aThe degrees of freedom were 34 for soil N, P and K, pH and stand. Since the other factors were imposed on both replicates at each location, averages of the two regression coefficients were used and the degrees of freedom were 16.

values of the regression coefficients change as certain uncontrolled factors vary in value. The relationships which attained significance at a probability level of 0.20 were entered into a polynomial equation as appropriate interactions.

The 0.20 probability restriction was imposed because of computing limitations. The uppermost limit on the number of variables considered at one time is fifty on the IBM 650 computer and because of the analytical procedures involved only eighteen of the indicated interactions in Table 27 could be evaluated in conjunction with the evaluated uncontrolled factors, applied fertilizer variables and interactions within these groups of factors. The interactions which attained a 0.30 level of probability but not 0.20 and were therefore eliminated from further analyses were $N_S \times NP$, $K_S \times K^2$, $pH \times PK$, $T \times N$, and $D_2 \times K$.

The other indicated interactions in Table 27 were entered into a regression equation also containing the uncontrolled variates affecting check leaf N percent as given in Table 21 and the variates from the regular second degree polynomial fitted to the individual replicate N percentages. A total of 44 variates were considered in the regression equation fitted to the 780 individual plot observations. Variates were eliminated from this final equation on the basis of a nonsignificant r -value relating the particular variate to total percent N or on the basis of a nonsignificant t -value for the regression coefficient of the variate in the final percent leaf N equation. The variates which were deleted on the basis of the simple r -value were NK , $y \times N_S$, $P_S \times N^2$, $P_S \times P^2$, $P_S \times NK$, $K_S \times K$, $pH \times HK$ and $D_2 \times P$. The variates

which were deleted on the basis of the t-value were K^2 , PK, pH, $P_S \times pH$, $T \times N_S$, $pH \times K$, $T \times N^2$, $y \times P^2$, $D_3 \times N$, $D_3 \times P$ and $D_3 \times P^2$. The amount of the total variation accounted for by the variates deleted on the basis of a t-value was nonsignificant according to a F-test.

The final equation which was considered to be adequate is shown in Table 28 with appropriate regression statistics. The coefficients of the applied variates were decoded, evaluated at zero input levels of the uncontrolled factors and transformed into bushels per acre per pound of input. This equation was highly significant at the 0.01 level of probability and attained an R^2 -value of 0.652. The coefficient of the K_S variate was nonsignificant, but was retained in the equation because it was included in interaction terms.

The interaction terms involving controlled and uncontrolled factors from this yield equation of 25 variates show the effect of the uncontrolled factors on applied N and P, although the major quantitative effect of the uncontrolled factors was on the level of percent leaf N. The effect of applied K was only to decrease leaf N concentration by a small but consistent amount. The effect of N and P on percent leaf N depended on soil N and K as well as the stress days occurring in stress period 2.

The regression equation will be interpreted with respect to how the effects of applied plant nutrients varied as the uncontrolled factors varied in value. Soil N appeared to

Table 28. Regression of all plot N percentages on observed and fertilizer variates and the correlation values of percent leaf N with each variate

| Variate | Equation $\hat{n} = b_0 + \sum b_i X_i$ ^a | Probability level of coefficient | $r_{yx_i} \cdot x_j$ ^b |
|---------------------------------|---|--|-----------------------------------|
| | 1.27164 ^c | | |
| N | 1.38255 X_1 | ** | 0.5576** |
| P | -0.68069 X_2 | * | -0.0889* |
| K | -0.03750 X_3 | + | -0.0383 ⁺ |
| N ² | -0.00392 X_4 | ** | -0.1374** |
| P ² | 0.00366 X_5 | * | -0.0370 |
| NP | 0.00086 X_6 | * | 0.0519 ⁺ |
| S | 13.44787 X_7 | * | -0.0391 ⁺ |
| S ² | -0.44847 X_8 | * | -0.0610 ⁺⁺ |
| N _S | 0.61520 X_9 | ++ | 0.0416 ⁺ |
| P _S | -3.30239 X_{10} | ** | 0.1237** |
| K _S | 0.03580 X_{11} | | 0.1568** |
| P _S x K _S | 0.00924 X_{12} | ** | 0.1866** |
| W | -17.37339 X_{13} | ** | 0.1442** |
| T | 0.19202 X_{14} | * | 0.1323** |
| Y | -4.08240 X_{15} | ** | -0.1224** |
| Y x P _S | 0.27347 X_{16} | ** | 0.1530** |
| D ₂ | 2.05900 X_{17} | * | -0.3881** |
| D ₃ | -0.67113 X_{18} | * | -0.4234** |
| D ₂ x D ₃ | -0.15509 X_{19} | * | -0.4074** |
| N _S x N | -0.00490 X_{20} | ** | 0.5288** |
| N _S x P | 0.00330 X_{21} | + | -0.0820* |
| N _S x N ² | 0.00003 X_{22} | + | -0.1229** |
| K _S x N | -0.00085 X_{23} | ** | 0.4598** |
| D ₂ x N | -0.00372 X_{24} | ** | 0.2369** |
| D ₂ x P ² | -0.00020 X_{25} | + | -0.3002** |

^a $b_i \times 10^2$. $i = 1 \dots 25$.

$b_{i,j} = 1 \dots 25$. $i \neq j$.

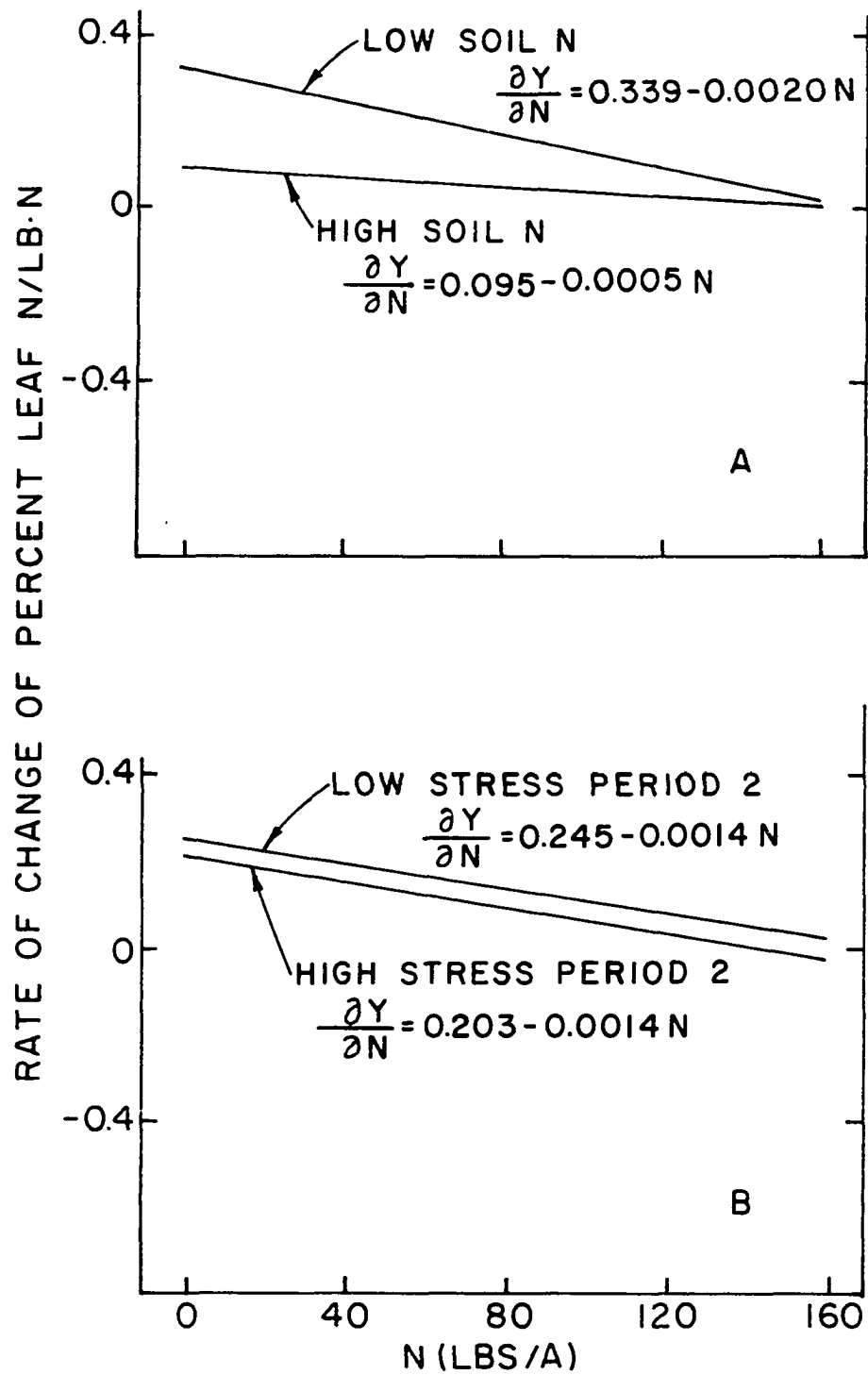
^cThis is b_0 , the constant in the regression equation.

substitute for fertilizer N as shown by the negative $N_s \times N$ interaction. The positive $N_s \times N^2$ interaction shows that the rate of decrease of the response to rates of fertilizer N lessened as soil N increased. This effect is shown in Figure 8A where the rate of change of percent leaf N is plotted against rates of applied N. Low soil N is 46 pounds and high soil N is 109 pounds per acre. All other factors, controlled and uncontrolled, were held at average experimental values. Any point on the respective lines is a solution of the first partial derivative of the percent N equation in Table 28 with respect to applied N. The general explanation and interpretation of this type of diagram was given in Section A, Part IV. This first partial derivative is a linear function for any given level of soil N.

Figure 8A which shows the rate of change of percent leaf N at two levels of soil N at different rates of applied N demonstrates that the initial response to applied N was greater at low levels of soil N. The response at low levels of soil N decreased at a greater rate than that at high levels of soil N. The rate of change of percent leaf N was not quite constant but changed little at a high level of soil N. In neither case was a maximum of percent leaf N reached in this plane.

The effect of stress days in stress period 2 is indicated by the negative $D_2 \times N$ interaction shown in Table 28.

Figure 8. Rate of change of percent leaf N with respect to applied N at two levels of soil N and two levels of stress day incidence in period 2 with all other factors at their average values

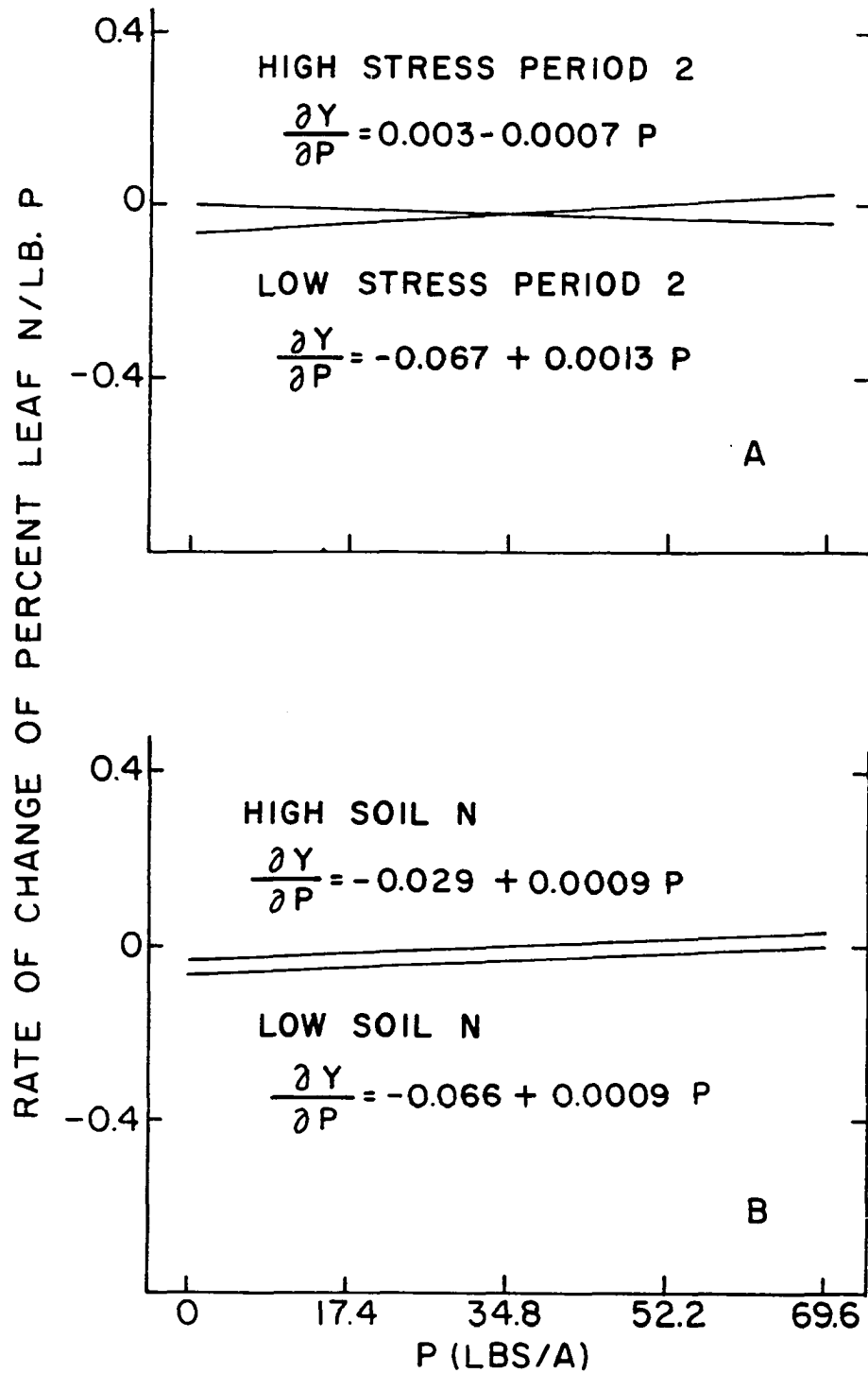


The effect is shown in Figure 8B for a low stress period with zero stress days incidence and a high stress period with 28 stress days and with all other factors being held at their average experimental values. The initial response to N at a low stress day incidence in stress period 2 was greater than at a high incidence. The rate of decrease of response to N was the same for both situations. The equality in the slope of the lines is due to the lack of a linear by quadratic interaction term involving stress period 2 and applied N. A maximum of leaf N concentration was reached with the high incidence of stress days at 144 pounds of N.

The effect of soil K on the change in percent leaf N due to applied N is indicated in Table 28 by the negative coefficient for the $K_s \times N$ interaction. As soil K increased, the increase in percent leaf N due to applied N was lessened. This may have been due to K being a limiting factor for plant growth at some locations.

The effect of applied P on percent leaf N was determined to some extent by soil N and the stress day incidence in stress period 2. The negative interaction of stress period 2 with the quadratic term for applied P as shown in Table 28 indicates the effect of stress days in period 2. This effect is shown in Figure 9A where it is noted that as stress day incidence increases, the increase in percent leaf N associated with increasing rates of applied P decreased. Figure 9A

Figure 9. Rate of change of percent leaf N with respect to applied P at two levels of stress day incidence in period 2 and two levels of soil N with all other factors at their average values



indicates that the effect of applied P on leaf N concentration is small, but the significance of the coefficients involving P as shown in Table 28 shows that the effect was consistent. The high stress period in Figure 9A had 28 days and the low stress period had none. The initial response due to applied P was negative when no stress days occurred, but a minimum occurred at 58 pounds of applied P and percent leaf N increased above this rate. The effect of applied P on percent leaf N was small when a high incidence of stress days occurred, and a maximum in leaf N concentration occurred at 4 pounds of applied P.

The effect of soil N on the response of percent leaf N to applied P is shown in Figure 9B with all other factors at their average experimental values. The initial response to applied P at 109 or 46 pounds of soil N was negative. However, the initial decrease was less when the amount of soil N increased. As can be seen in Figure 9B the effect of soil N on the response due to applied P was small and that the rate of change of percent leaf N due to applied P differed by a constant amount. The reason as to why the dilution effect of applied P lessened at higher levels of soil N is not apparent from these data.

The effects of various levels of the uncontrolled factors on the change in percent leaf N due to applied fertilizer were not primarily on the differential response to applied N and P.

The major quantitative effects of the uncontrolled factors were on the level of leaf N concentration. These effects of the various levels of the uncontrolled factors on percent leaf N obtained from applied N, P and K are illustrated in Figures 10, 11, 12 and 13 by predicted values of percent leaf N. Percent leaf N responded differentially to applied N and P as determined by the uncontrolled factors and, therefore, the level of K was held at a constant amount of 41.6 pounds per acre for all illustrations and N and P were allowed to vary.

Figure 10 illustrates percent leaf N as a function of applied N and P when soil N, P and K values are 46, 0.5 and 48 pounds per acre respectively. All other factors were held at their average values and the incidence of stress days in any period was zero. The lowest percent leaf N value, 1.98, was predicted at zero pounds of N and 69.6 pounds of P per acre. The highest percent leaf N value, 3.00, was predicted at 160 pounds of N and zero pounds of P per acre.

The effect of a high incidence of stress days in all stress periods on percent leaf N with all other factors remaining the same as in Figure 10 is illustrated in Figure 11. The stress days occurring in stress periods 1, 2 and 3 were 20, 28 and 21 days respectively. The effect of applied N was more curvilinear than that obtained for the previous figure. The effect of applied P decreased percent leaf N at an increasing rate, whereas in Figure 10 applied P decreased

Figure 10. Predicted percent leaf N surface as a function of applied N and P with soil N, P and K at low observed values, zero incidence of stress days and all other factors at their average observed values

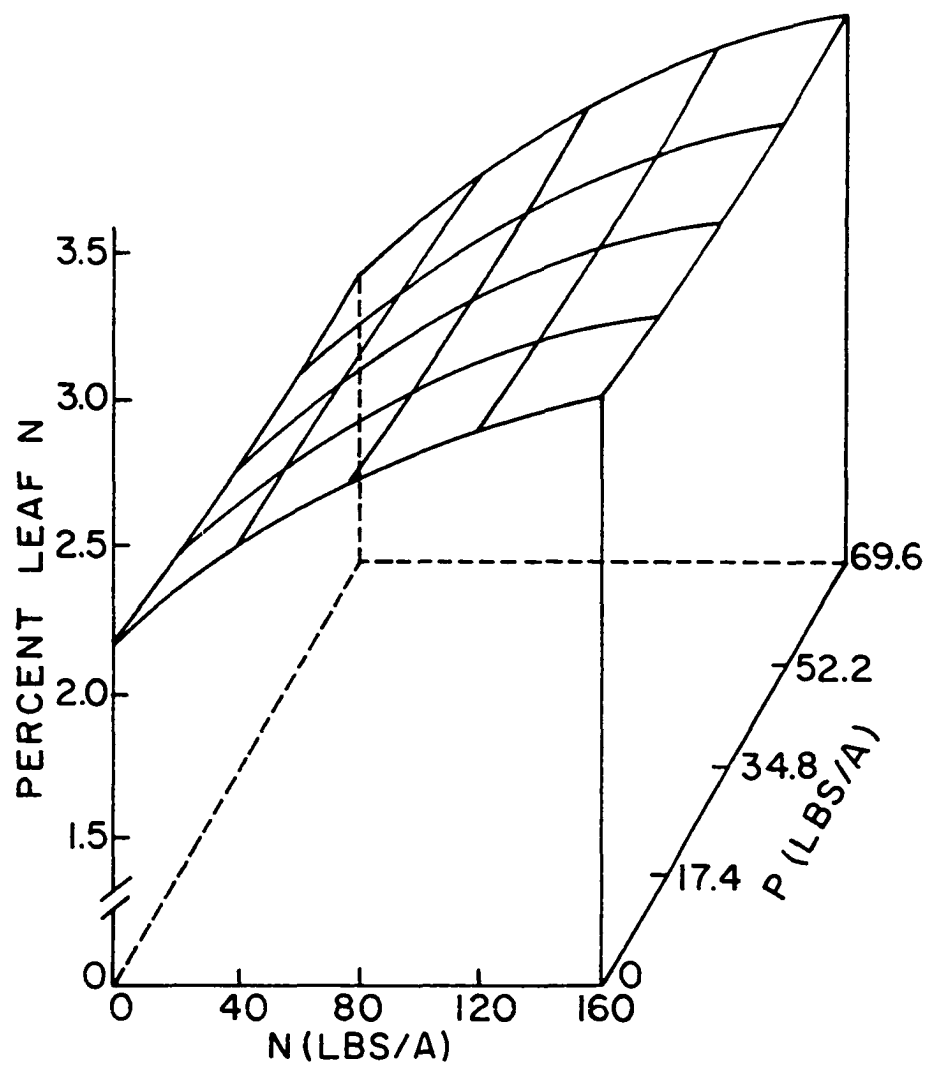


Figure 11. Predicted percent leaf N surface as a function of applied N and P with soil N, P and K at low observed values, incidence of stress days at high observed values and all other factors at their average observed values

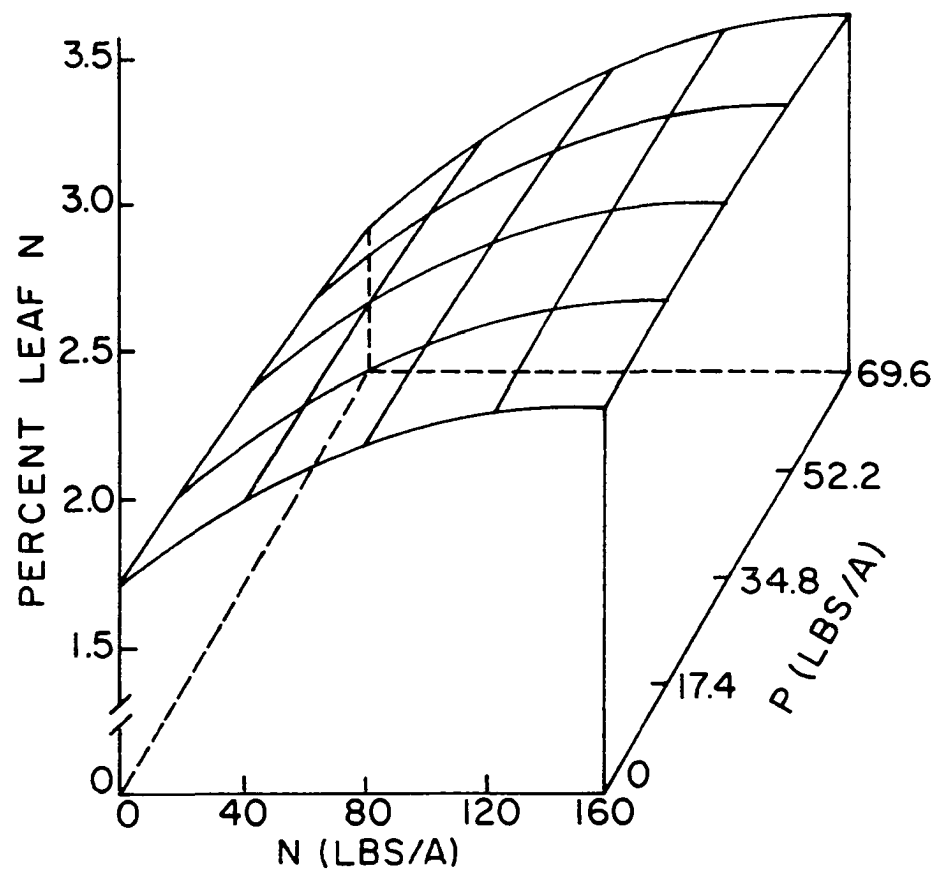


Figure 12. Predicted percent leaf N surface as a function of applied N and P with soil N, P and K at high observed values, zero incidence of stress days and all other factors at their average observed values

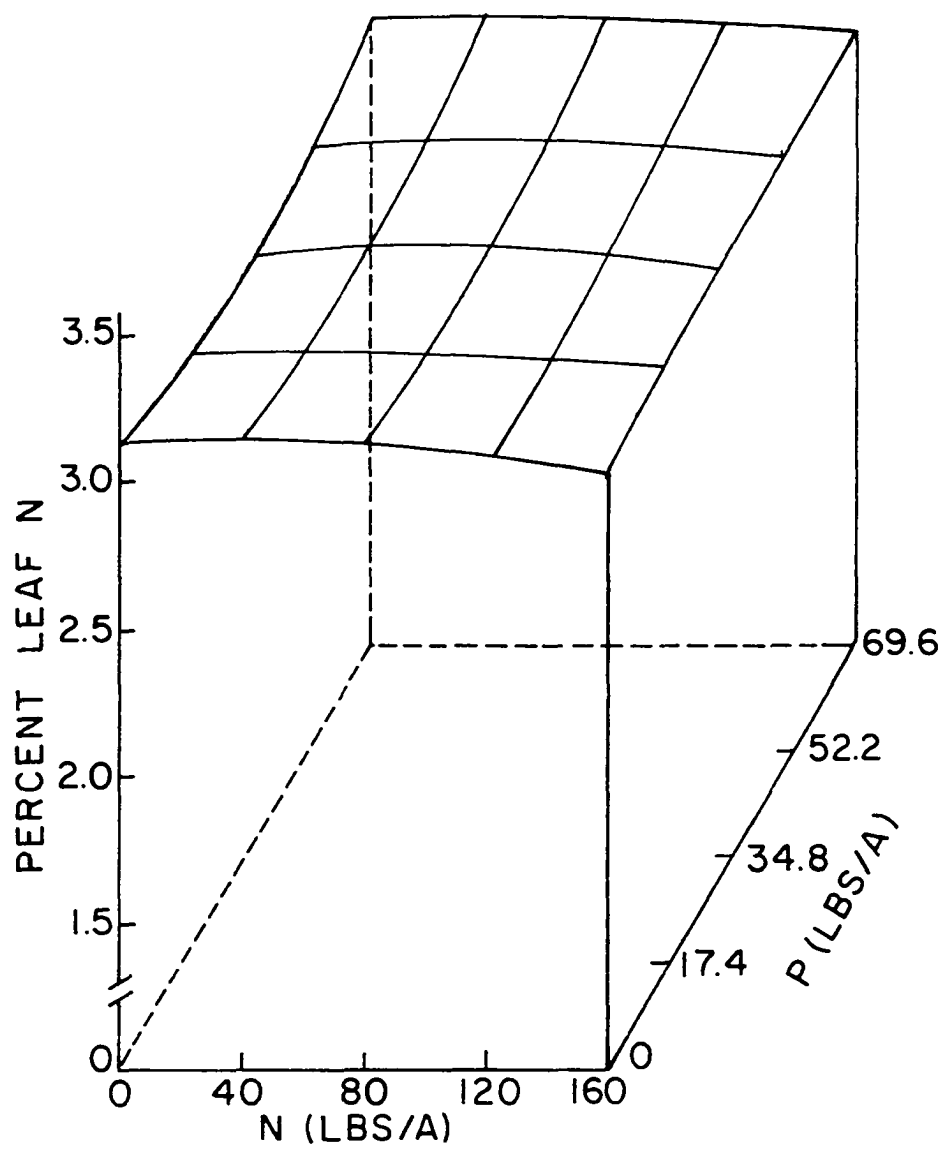
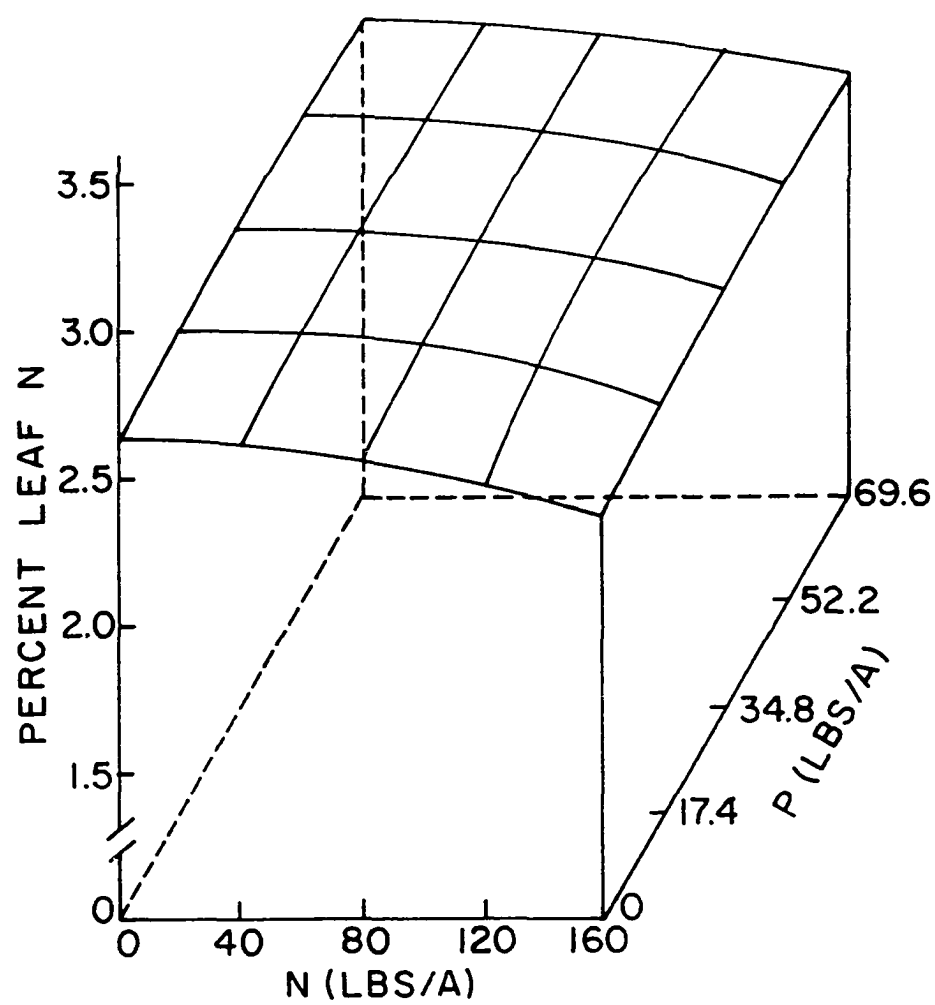


Figure 13. Predicted percent leaf N surface as a function of applied N and P with soil N, P and K at high observed values, incidence of stress days at high observed values and all other factors at their average observed values



percent leaf N at a decreasing rate. It is very noticeable from comparing Figures 10 and 11 that the major quantitative effect of weather as characterized by stress days was on the level of percent leaf N. The lowest percent leaf N value, 1.51 was predicted at zero pounds of N and 69.6 pounds of P and the highest percent leaf N value, 2.31, was predicted at 160 pounds of N and zero pounds of P.

Figure 12 illustrates percent leaf N as a function of applied N and P at zero incidence of stress days and at high levels of soil N, P and K. These soil values were 109, 18.4 and 320 pounds per acre respectively. All other factor values were the same as in the previous figures. The most noticeable characteristics are that percent leaf N is high over the entire surface and that the effects of applied N and P were very small. The effect of applied N was to decrease percent leaf N, and the effect of applied P was to increase percent leaf N. The lowest percent leaf N value, 3.02 was predicted at 160 pounds of N and 17.4 pounds of P per acre and the highest value, 3.13, was predicted at 40 pounds of N and zero pounds of P per acre.

The effect of a high incidence of stress days on percent leaf N with all other factor values remaining the same as in Figure 12 is shown in Figure 13. The largest effect was the overall lowering of percent leaf N values. The effect of applied N was to decrease percent leaf N by a greater amount

although the rate of decrease is the same as in Figure 12. The effect of applied P was to decrease leaf N at a decreasing rate. The lowest percent leaf N value, 2.40, was predicted at 160 pounds of N and zero pounds of applied P, and the highest value, 2.65, was predicted at zero pounds of N and 17.4 pounds of P.

The analyses and illustrations of the data indicate that the effect of uncontrolled factors on the response to applied N, P and K was not as large quantitatively as the effect on the general level of percent leaf N. Figures 8A, 10 and 12 illustrate that soil N substitutes for applied N and the increase of percent leaf N due to applied N decreases as soil N increases. This was the largest effect of uncontrolled factors on percent leaf N response to applied N and P. Weather also affected the percent leaf N response to applied N and P, but the effect was greatest on the general level of percent leaf N. The effect of weather as characterized by stress days in stress periods is illustrated in Figures 8B, 9B, 10 and 11.

The general effect of high levels of soil factors was to increase the level of percent leaf N. The effect of a high incidence of stress days was to decrease the level of percent leaf N. The effect of the other uncontrolled factors on percent leaf N may be ascertained from Table 28 by the sign and value of the respective coefficients.

C. Concentration of P in Corn Leaves

The concentration of P in the corn leaf, expressed as percent leaf P, was affected by soil, weather, fertilizer, management and the interactions of components of these factors. Factors affecting percent leaf P, other than applied fertilizer, were selected on the basis of their effect on leaf P percentages obtained with zero fertilizer applied.

The same factors used in the analysis of percent leaf N were considered in evaluating variations in percent leaf P due to applied N, P and K and uncontrolled factors. Values of the factors considered in this analysis and methods of characterization are in Section A dealing with corn yield. The factors affecting percent leaf P and the methods of selection are discussed in succeeding paragraphs.

1. Selection of soil variables

The soil variables were selected on the basis of simple correlation with check percent leaf P obtained from each replicate. The correlations of check percent leaf P with various soil test values are shown in Table 29. The highest correlation was obtained between check leaf P and available P. Check leaf P was also related to subsoil P, but since the total subsoil P was highly related to the surface soil test value only the surface value was retained for further analyses.

Check leaf P was related to measurements of nitrifiable

Table 29. Simple correlation values showing the relation of check percent leaf P to surface soil test values and to selected soil test variables by depth

| Soil test variable ^a | Depth in inches | | | | |
|---------------------------------|--------------------|--------|--------------------|---------------------|--------|
| | 0-6 | 6-12 | 12-18 | 18-24 | 24-36 |
| Initial nitrate | -0.049 | | | | |
| Nitrifiable N(d) | 0.249 ⁺ | | | | |
| Nitrifiable N(m) | 0.267 ⁺ | -0.007 | -0.335* | -0.266 ⁺ | -0.196 |
| Available P(d) | 0.404* | 0.332* | 0.244 ⁺ | 0.372* | 0.404* |
| Exchangeable K(d) | -0.123 | | | | |
| Exchangeable K(m) | 0.150 | 0.036 | -0.095 | -0.069 | -0.122 |
| pH | 0.094 | | | | |

^ad and m designations refer to measurements made on air dry and field moist samples respectively.

N made on both dry and moist samples. The measurements made on moist samples were retained as these had a slightly higher correlation value and these were used in previous analyses.

Check percent leaf P was not related to exchangeable K or pH but these were retained for further examination to ascertain if they interacted with the other soil and uncontrolled factors.

2. Selection of variables other than soil

Other factors evaluated for their effect on check percent leaf P were stand (plant density), planting date, yield potential, wind damage and weather as characterized by stress

days in stress periods. The degree of correlation of check percent leaf P with these factors is shown in Table 30. Check leaf P was not related to stand, planting date, yield potential and stress days in period 1 as indicated by the nonsignificant correlation values.

Table 30. Simple correlation values relating check percent leaf P to stand, planting date, yield potential, wind damage factor and stress days in periods 1, 2 and 3

| | |
|-----------------|----------|
| Stand | -0.061 |
| Planting date | -0.037 |
| Yield potential | -0.175 |
| Wind damage | 0.382* |
| Stress period 1 | -0.047 |
| Stress period 2 | -0.554** |
| Stress period 3 | -0.543** |

A positive relation with the wind damage factor indicates that this adjustment accounts for a large degree of the depression of percent leaf P in the three experiments in which this damage occurred prior to silking. The effect of stress days on percent leaf P was negative in stress periods 2 and 3 as indicated by the correlation values. This may be due to a decrease of soil solution, and as the available P originally in solution is removed a lesser amount of P is available although the P concentration in the soil solution may remain the same. A differential effect on the amount of top growth of the corn and amount of P available to the plant may also be

a factor.

3. Combined effect of uncontrolled variables on check percent leaf P

The purpose of the previous correlation analyses was to ascertain which variables accounted for variation in the check leaf P percentages. These variables and appropriate interactions were utilized in a multiple regression analysis to ascertain the amount of variation in check leaf P percentages accounted for by these variables. Indication of an interaction was obtained by graphical and covariance analyses as described in Section A, Part IV.

Variates which had a significance at a probability level of 0.30 as determined by a t-test for the simple or multiple relationship were retained in the multiple regression equation. The multiple regression equation variates and values of the regression coefficients are presented in Table 31. This table also shows singular relationships of check percent leaf P with the variates through simple correlation values. An R^2 -value of 0.878 was obtained for this regression equation containing 17 variates. This regression mean square was significant at the 0.01 level of probability. The range of check percent leaf P was from 0.171 to 0.327 percent.

This regression equation had 10 coefficients that attained significance at some level of probability. Neither the regression coefficients of pH or stress period 1 nor the

Table 31. Regression of check percent leaf P on observed variates, significance level of regression coefficients and correlation values and their significance obtained from relating check percent leaf P to each variate

| Variate | Equation $\hat{p} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{yx_i} \cdot x_j^a$ |
|---------------------------------|--|-------------------------------------|------------------------|
| | 1.25664 ^b | | |
| N _S | +0.001357 X ₁ | ** | 0.267+ |
| P _S | -0.015378 X ₂ | + | 0.404* |
| K _S | +0.000256 X ₃ | + | 0.150 |
| P _S x K _S | +0.000015 X ₄ | | 0.339* |
| pH | -0.010966 X ₅ | | 0.094 |
| P _S x pH | +0.001680 X ₆ | + | 0.422* |
| S | -0.119351 X ₇ | * | -0.061 |
| S ² | +0.003921 X ₈ | * | -0.068 |
| T | -0.000791 X ₉ | + | -0.037 |
| Y | -0.010529 X ₁₀ | * | -0.175 |
| P _S x Y | +0.000769 X ₁₁ | ** | 0.450** |
| W | +0.018511 X ₁₂ | | 0.382* |
| D ₁ | -0.001052 X ₁₃ | | -0.047 |
| D ₂ | +0.000472 X ₁₄ | | -0.554** |
| D ₃ | -0.000798 X ₁₅ | | -0.543** |
| D ₁ x D ₂ | -0.000192 X ₁₆ | ** | -0.440** |
| D ₂ x D ₃ | +0.000004 X ₁₇ | | -0.524** |

^a $i, j = 1 \dots 17. i \neq j.$

^bThis is b_0 , the constant in the regression equation.

correlation coefficients relating check leaf P to these variates were significant. However, they were retained because of their occurrence in interactions. The effect that these factors may have on total yield or on the change in yield due to applied N, P and K is of primary importance and the analyses

of these effects are presented in a following section.

4. Effect of applied N, P and K

The presence of treatment effect on leaf P percentages from each experiment was determined by a simple analysis of variance for each experiment. The analysis of variance for each 1959 experiment is presented in Table 32 and for each 1960 experiment in Table 33.

Treatment effects attained a probability level of 0.01 in 1959 Experiments 1 and 3, 0.05 in Experiments 2 and 6 and 0.30 in Experiment 5. Treatment had no effect in Experiment 4 as indicated by the nonsignificant treatment mean square.

Table 32. Analysis of variance of percent leaf P for each of six experiments conducted in 1959

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|----------|-----------|
| | | 1 | 2 | 3 |
| Total | 37 | | | |
| Replicates | 1 | 0.00003 | 0.00008 | 0.00484** |
| Treatments | 18 | 0.00102** | 0.00095* | 0.00103** |
| Error | 18 | 0.00008 | 0.00036 | 0.00019 |
| | | 4 | 5 | 6 |
| Total | 37 | | | |
| Replicates | 1 | 0.00112* | 0.00006 | 0.00014 |
| Treatments | 18 | 0.00026 | 0.00062+ | 0.00034* |
| Error | 18 | 0.00020 | 0.00041 | 0.00014 |

The low stand level may have been a factor for lack of treatment effect in Experiment 4. A difference between replicates is indicated in Table 32 for 1959 Experiments 3 and 4. There are no apparent reasons for these differences.

Table 33. Analysis of variance of percent leaf P for each of twelve experiments conducted in 1960

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|-----------------------|----------------------|
| | | 1 | 2 | 3 |
| Total | 45 | | | |
| Replicates | 1 | 0.00006 | 0.00012 | 0.00209* |
| Treatments | 22 | 0.00106** | 0.00109** | 0.00133** |
| Error | 22 | 0.00027 | 0.00010 | 0.00030 |
| | | 4 | 5 | 6 |
| Total | 45 | | | |
| Replicates | 1 | 0.00047 ⁺⁺ | 0.00080 ⁺⁺ | 0.00417** |
| Treatments | 22 | 0.00155** | 0.00137** | 0.00030 |
| Error | 22 | 0.00012 | 0.00023 | 0.00038 |
| | | 7 | 8 | 9 |
| Total | 45 | | | |
| Replicates | 1 | 0.00052 ⁺ | 0.00001 | 0.00026 ⁺ |
| Treatments | 22 | 0.00093** | 0.00194** | 0.00039* |
| Error | 22 | 0.00026 | 0.00044 | 0.00017 |
| | | 10 | 11 | 12 |
| Total | 45 | | | |
| Replicates | 1 | 0.00133* | 0.00020 | 0.00003 |
| Treatments | 22 | 0.00058** | 0.00141 ⁺ | 0.00136* |
| Error | 22 | 0.00017 | 0.00059 | 0.00050 |

Treatment effect attained a probability level of 0.01 in 1960 Experiments 1, 2, 3, 4, 5, 7, 8 and 10, 0.05 in Experiments 9 and 12 and 0.30 in Experiment 11. There was a lack of treatment effect in Experiment 6 and no apparent reason can be given for this. Replicate differences are indicated in Experiments 3, 4, 5, 6, 7, 9 and 10. Some of these differences can be attributed to differences in soil P between replicates but not in all experiments. The difference in soil P between these replicates ranged from 0.5 to 7.5 pounds per acre.

Stand may have had some influence on treatment effect and replicate differences. However, no adjustment for stand was made in these analyses of variance by experiment as stand is to be included in future regression analysis as an independent variable.

The preceding analyses indicated different effects of treatments among experiments. A combined analysis of variance for the 1959 experiments shown in Table 34 indicates this to a minor degree. The pooled errors were heterogenous for 1959. This leaves the significance of the treatment by experiments term in doubt. By assuming the highest tabulated F-value for this comparison at a single experiment's degrees of freedom of 18 and 18 it does not attain significance. If the pooled errors were homogenous, the probability level would be 0.25. Therefore it is doubtful whether the effect of treatments varied among experiments in 1959. The

Table 34. Combined analysis of variance of percent leaf P for 1959 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|----------------------|
| Total | 227 | |
| Experiments | 5 | 0.03894** |
| Treatments/Experiments | 108 | 0.00070 |
| Treatments | 18 | 0.00272** |
| Treatments x Experiments | 90 | 0.00030 ^a |
| Replicates/Experiments | 6 | 0.00104 |
| Replicates | 1 | 0.00268 |
| Replicates x Experiments | 5 | 0.00072 |
| Error | 108 | 0.00023 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for this variance comparison cannot be ascertained. At 18 and 18 degrees of freedom it does not attain any significance level.

significance of the experiments' and treatments' mean squares indicates that the concentration of leaf P varied among experiments and that consistent differences due to treatments occurred.

Table 35 shows the combined analysis of variance for the 1960 experiments. The problem of heterogeneity of pooled errors is again present. The significance of the treatments by experiments term is between the 0.10 and 0.01 level of probability. This term indicates that the effect of treat-

Table 35. Combined analysis of variance of percent leaf P for 1960 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|----------------------|
| Total | 551 | |
| Experiments | 11 | 0.03799** |
| Treatments/Experiments | 264 | 0.00111 |
| Treatments | 22 | 0.00713** |
| Treatments x Experiments | 242 | 0.00056 ^a |
| Replicates/Experiments | 12 | 0.00084 |
| Replicates | 1 | 0.00002 |
| Replicates x Experiments | 11 | 0.00091 |
| Error | 264 | 0.00029 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for this variance comparison cannot be ascertained. At 22 and 22 degrees of freedom it attains a significance level of 0.10.

ments differed among experiments. The significance of the comparison of the mean square for treatments with that of the treatments by experiments indicates that treatment differences are consistent among experiments. The significant mean square for experiments indicates that the concentration of leaf P varied among experiments.

The foregoing analyses indicated that treatments were effective in changing leaf P concentration but that the effect differed among experiments. The individual analysis of

variance also indicated that differences occurred between replicates within experiments. In order to evaluate soil effects the data are subsequently analyzed on an individual replicate and plot basis by multiple regression techniques.

Although it has been shown that treatments of fertilizer N, P and K affected leaf P concentration, the individual effects of applied N, P and K on percent leaf P have not been indicated. By the application of multiple regression analysis the yield equation, $p = B_0 + B_1N + B_2P + B_3K + B_4N^2 + B_5P^2 + B_6K^2 + B_7NP + B_8NK + B_9PK$, was fitted to the data of each replicate to ascertain the individual effects of applied N, P and K on percent leaf P, p. The effects of these applied nutrients are discussed in subsequent paragraphs by noting only those regression coefficients that attained a significance at a probability of 0.30 or above.

The regression coefficients, their significance and the R^2 -value for each regression equation for each replicate appear in Table 36. In the 1959 experiments the effect of N on leaf P concentration as indicated by the significant coefficients was to increase percent leaf P. The effect was linear in Experiment 1 and Replicates 2 of Experiment 2, 1 of Experiment 3, 2 of Experiment 4, 2 of Experiment 5 and 2 of Experiment 6. Applied N decreased percent leaf P linearly in Replicate 1 of Experiment 6. The effect of P was to increase percent leaf P in Experiments 1, 2 and 3 and in Replicates 2

Table 36. Regression coefficients^a and R²-values obtained from fitting a second degree polynomial with interactions to the leaf P percentage data from each replicate of each experiment

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|----------------------|
| | | 1 | 2 | 3 |
| 1 | b ₀ | 0.1973 | 0.2296 | 0.2415 |
| | b ₁ | 0.0078** | 0.0775* | 0.0110 ⁺ |
| | b ₂ | 0.1969** | 0.1232 ⁺⁺ | 0.0369* |
| | b ₃ | -0.0183 | -0.0920 ⁺⁺ | -0.0136 |
| | b ₄ | 0.0000 | -0.0003* | -0.0001 |
| | b ₅ | -0.0016** | -0.0003 | 0.0006 |
| | b ₆ | 0.0000 | 0.0014** | 0.0000 |
| | b ₇ | 0.0000 | -0.0003 ⁺ | 0.0002 |
| | b ₈ | 0.0002 ⁺ | -0.0001 | 0.0001 |
| | b ₉ | -0.0002 | -0.0011* | -0.0004 |
| | R ² | 0.941 | 0.902 | 0.739 |
| 2 | b ₀ | 0.1969 | 0.2587 | 0.2058 |
| | b ₁ | 0.0064** | 0.0108 ⁺ | 0.0724** |
| | b ₂ | 0.0902** | 0.0289* | 0.0071 ⁺⁺ |
| | b ₃ | 0.0703* | -0.0601 ⁺ | 0.0126 ⁺ |
| | b ₄ | 0.0000 | 0.0000 | -0.0002 ⁺ |
| | b ₅ | -0.0015** | 0.0000 | -0.0002 |
| | b ₆ | -0.0005 ⁺ | -0.0001 | -0.0005 |
| | b ₇ | 0.0006** | 0.0003 | 0.0000 |
| | b ₈ | -0.0001 | 0.0000 | 0.0003 |
| | b ₉ | 0.0004 | 0.0007 | 0.0011 ⁺ |
| | R ² | 0.938 | 0.668 | 0.792 |
| | | 4 | 5 | 6 |
| 1 | b ₀ | 0.3277 | 0.2767 | 0.2935 |
| | b ₁ | 0.0185 | 0.0225 ⁺ | -0.0038 ⁺ |
| | b ₂ | 0.0567 | 0.2317** | 0.0258 |
| | b ₃ | -0.1447* | -0.0676 | -0.0459 |

^avalues of b_i x 10². i = 1 . . . 9.

Table 36. (Continued)

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|-----------------------|
| | | 4 | 5 | 6 |
| 1 | b ₄ | -0.0001 | -0.0002 ⁺ | 0.0001 |
| | b ₅ | -0.0002 | -0.0012 ⁺ | -0.0006 |
| | b ₆ | 0.0011 ⁺⁺ | 0.0001 | 0.0008 ⁺ |
| | b ₇ | -0.0002 | 0.0003 | 0.0003 |
| | b ₈ | 0.0000 | 0.0005 ⁺⁺ | -0.0002 |
| | b ₉ | -0.0001 | 0.0001 | 0.0001 |
| | R ² | 0.662 | 0.887 | 0.578 |
| 2 | b ₀ | 0.2960 | 0.2917 | 0.3004 |
| | b ₁ | 0.0051 ⁺⁺ | 0.0339 ⁺ | 0.0054 ^{**} |
| | b ₂ | 0.0176 ⁺ | -0.0420 | -0.0146 ⁺ |
| | b ₃ | -0.0245 | 0.0983 | -0.0103 |
| | b ₄ | -0.0007 | -0.0001 | 0.0000 |
| | b ₅ | -0.0005 | 0.0003 | -0.0004 |
| | b ₆ | 0.0003 | -0.0007 | -0.0002 |
| | b ₇ | 0.0004 ⁺⁺ | 0.0002 | 0.0003 ⁺ |
| | b ₈ | 0.0000 | -0.0002 | 0.0000 |
| | b ₉ | 0.0000 | -0.0001 | 0.0009 ⁺⁺ |
| | R ² | 0.663 | 0.414 | 0.706 |
| | | 1960 Experiments | | |
| | | 1 | 2 | 3 |
| 1 | b ₀ | 0.2514 | 0.1962 | 0.2709 |
| | b ₁ | 0.0585 ^{**} | 0.0290 ^{**} | 0.1104 ^{**} |
| | b ₂ | -0.0180 [*] | 0.0687 [*] | -0.0269 ⁺⁺ |
| | b ₃ | 0.0359 ⁺ | 0.0930 | 0.0153 |
| | b ₄ | -0.0002 ⁺ | 0.0000 | -0.0004 [*] |
| | b ₅ | 0.0009 | -0.0006 ⁺ | 0.0001 |
| | b ₆ | -0.0004 | -0.0006 ⁺ | 0.0001 |
| | b ₇ | 0.0002 ⁺ | 0.0005 ^{**} | 0.0004 ⁺⁺ |
| | b ₈ | -0.0001 | -0.0004 ^{**} | -0.0005 [*] |
| | b ₉ | -0.0004 | -0.0002 | 0.0003 |
| | R ² | 0.716 | 0.917 | 0.831 |

Table 36. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|-----------------------|----------------------|-----------------------|
| | | 1 | 2 | 3 |
| 2 | b ₀ | 0.2497 | 0.2131 | 0.3011 |
| | b ₁ | 0.0609* | 0.0050** | 0.0624** |
| | b ₂ | -0.1178** | 0.0655** | -0.0029 |
| | b ₃ | 0.1164 ⁺ | -0.0039 ⁺ | -0.0864** |
| | b ₄ | -0.0003 ⁺⁺ | 0.0000 | -0.0003 ⁺⁺ |
| | b ₅ | 0.0022* | -0.0007 ⁺ | -0.0002 |
| | b ₆ | -0.0014* | 0.0001 | 0.0006 ⁺ |
| | b ₇ | 0.0000 | 0.0004** | 0.0003 ⁺⁺ |
| | b ₈ | 0.0001 | 0.0000 | 0.0000 |
| | b ₉ | 0.0002 | 0.0000 | 0.0001 |
| | R ² | 0.724 | 0.836 | 0.790 |
| | | 4 | 5 | 6 |
| 1 | b ₀ | 0.2044 | 0.1868 | 0.2818 |
| | b ₁ | 0.0203** | 0.0727** | -0.0381 |
| | b ₂ | 0.1135** | 0.1371** | -0.0139** |
| | b ₃ | -0.0217 | -0.0668* | -0.0281 |
| | b ₄ | -0.0001 | -0.0002 | 0.0002 ⁺ |
| | b ₅ | -0.0006 | -0.0009 | 0.0007 |
| | b ₆ | 0.0001 | 0.0012 ⁺⁺ | 0.0000 |
| | b ₇ | 0.0003 ⁺ | -0.0003 ⁺ | -0.0001 |
| | b ₈ | 0.0002 ⁺ | -0.0001 | 0.0001 |
| | b ₉ | 0.0000 | 0.0002 | 0.0006 ⁺ |
| | R ² | 0.854 | 0.775 | 0.644 |
| 2 | b ₀ | 0.2030 | 0.2253 | 0.2790 |
| | b ₁ | 0.0117** | 0.0758** | -0.0523 ⁺ |
| | b ₂ | 0.1538** | 0.0523** | 0.1301 |
| | b ₃ | -0.0397 | -0.1013 | 0.0297 |
| | b ₄ | -0.0001 | -0.0003* | 0.0003* |
| | b ₅ | -0.0015* | -0.0003 | -0.0015* |
| | b ₆ | 0.0006 ⁺ | 0.0008* | -0.0002 |
| | b ₇ | 0.0004** | -0.0001 ⁺ | 0.0002 ⁺ |
| | b ₈ | 0.0000 | 0.0000 | 0.0000 |
| | b ₉ | -0.0003 | 0.0009** | -0.0007* |
| | R ² | 0.886 | 0.903 | 0.592 |

Table 36. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|----------------------|----------------------|-----------------------|
| | | 7 | 8 | 9 |
| 1 | b ₀ | 0.1759 | 0.2565 | 0.2415 |
| | b ₁ | 0.0462 ⁺⁺ | -0.0082 | 0.0185** |
| | b ₂ | 0.0642** | 0.1807** | 0.0110 |
| | b ₃ | 0.0803 ⁺ | -0.1064 ⁺ | -0.0480 |
| | b ₄ | -0.0002 ⁺ | -0.0001 | -0.0001 |
| | b ₅ | -0.0001 | -0.0025** | -0.0006 |
| | b ₆ | 0.0000 | 0.0012 ⁺ | 0.0003 |
| | b ₇ | 0.0019 ⁺ | 0.0006* | 0.0002 ⁺ |
| | b ₈ | -0.0004** | 0.0003 ⁺ | 0.0000 |
| | b ₉ | -0.0009** | -0.0011* | 0.0005 ⁺ |
| | R ² | 0.800 | 0.823 | 0.613 |
| 2 | b ₀ | 0.2084 | 0.2411 | 0.2422 |
| | b ₁ | 0.0215* | 0.0405 | -0.0234 ⁺⁺ |
| | b ₂ | 0.1119** | 0.0820** | 0.0830 ⁺ |
| | b ₃ | -0.0197* | 0.1006 | -0.0121 |
| | b ₄ | -0.0002 ⁺ | -0.0004* | 0.0001 |
| | b ₅ | -0.0013 ⁺ | -0.0009 | -0.0009 ⁺ |
| | b ₆ | 0.0001 | -0.0009 ⁺ | -0.0001 |
| | b ₇ | 0.0006* | 0.0010** | 0.0001 |
| | b ₈ | 0.0001 | 0.0002 | 0.0003* |
| | b ₉ | -0.0001 | 0.0005 ⁺ | -0.0003 |
| | R ² | 0.766 | 0.866 | 0.547 |
| | | 10 | 11 | 12 |
| 1 | b ₀ | 0.2865 | 0.2627 | 0.2626 |
| | b ₁ | 0.0557* | 0.0565** | -0.0914 ⁺ |
| | b ₂ | -0.0026* | 0.0840 | 0.1954** |
| | b ₃ | 0.0639 ⁺ | -0.0551 | -0.0254 |
| | b ₄ | -0.0003 ⁺ | -0.0002 ⁺ | 0.0004 ⁺ |
| | b ₅ | 0.0004 | -0.0011 | -0.0009 |
| | b ₆ | -0.0005 | 0.0008 ⁺ | 0.0007 |
| | b ₇ | 0.0001 | 0.0003 ⁺ | -0.0006 ⁺⁺ |
| | b ₈ | -0.0001 | 0.0000 | -0.0001 |
| | b ₉ | -0.0001 | -0.0005 | -0.0002 |
| | R ² | 0.622 | 0.618 | 0.679 |

Table 36. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|----------------------|-----------------------|----------------------|
| | | 10 | 11 | 12 |
| 2 | b ₀ | 0.2935 | 0.2687 | 0.2542 |
| | b ₁ | 0.0044** | 0.0440** | -0.0617* |
| | b ₂ | 0.0001** | -0.0883 ⁺⁺ | 0.1201** |
| | b ₃ | 0.0334 ⁺ | 0.0379 | 0.0006 |
| | b ₄ | -0.0001 | -0.0003 | 0.0005** |
| | b ₅ | 0.0004 | 0.0010 | -0.0011 ⁺ |
| | b ₆ | -0.0004 ⁺ | -0.0003 | -0.0005 |
| | b ₇ | 0.0003* | 0.0009** | -0.0003 ⁺ |
| | b ₈ | 0.0002 ⁺⁺ | 0.0000 | 0.0002 ⁺ |
| | b ₉ | -0.0002 | -0.0003 | -0.0005 ⁺ |
| | R ² | 0.814 | 0.709 | 0.818 |

of Experiment 4 and 1 of Experiment 5, but the positive effect decreased at higher rates of P in Experiment 1 and Replicate 1 of Experiment 5. Applied P decreased leaf P linearly in Replicate 2 of Experiment 6. The effect of applied K on percent leaf P was diverse as indicated by the significant coefficients for K and the second degree term for K. Percent leaf P increased due to applied K in Replicate 2 of Experiment 3 and at higher rates of K in Replicate 1 of Experiment 6. Applied K increased percent leaf P in Replicate 2 of Experiment 1 but this effect was curvilinear as indicated by the negative coefficient for the quadratic term for K. Percent leaf P decreased due to applied K in Replicate 2 of Experiment 2 and this effect decreased at a decreasing rate in Replicates 1 of

Experiment 2 and 1 of Experiment 4.

The results from 1959 indicate in general that applied N and P increased percent leaf P. The effect of K was more diverse. Similar results were obtained in 1960 as shown in Table 36 and indicated by the significant regression coefficients. Applied N increased percent leaf P linearly in Experiments 2 and 4 and Replicates 1 of Experiment 5, 1 of Experiment 9, 2 of Experiment 10 and 2 of Experiment 11. The effect of N increased leaf P concentration at a decreasing rate in Experiments 1, 3 and 7 and Replicates 2 of Experiment 5, 1 of Experiment 10 and 1 of Experiment 11. Applied N decreased the concentration of P in the leaf in Replicate 2 of Experiment 9 and this effect was at a decreasing rate in Replicate 2 of Experiment 6 and in Experiment 12. Applied N increased percent leaf P at higher rates of N in Replicate 1 of Experiment 6 but the opposite occurred in Replicate 2 of Experiment 8.

Fertilizer P increased percent leaf P linearly in Experiment 5 and Replicates 1 of Experiment 4, 1 of Experiment 7, 2 of Experiment 8, 2 of Experiment 10 and 1 of Experiment 12. The increase in percent leaf P due to applied P was at a decreasing rate in Experiment 2 and Replicates 2 of Experiment 4, 2 of Experiment 7, 1 of Experiment 8, 2 of Experiment 9 and 2 of Experiment 12. A linear decrease in percent leaf P due to applied P was indicated in Replicates 1 of Experiment 1, 1 of

Experiment 3, 1 of Experiment 6, 1 of Experiment 10 and 2 of Experiment 11 but this decrease was at a decreasing rate in Replicate 2 of Experiment 1. Applied P appeared to decrease percent leaf P at high rates of P in Replicate 2 of Experiment 6.

Applied K increased percent leaf P linearly in Replicates 1 of Experiment 1, 1 of Experiment 7 and 1 of Experiment 10. The increase due to K was at a decreasing rate in Replicates 2 of Experiment 1 and 2 of Experiment 10. A linear decrease due to K was indicated in Replicate 2 of Experiment 2. A decrease in percent leaf P at a decreasing rate due to K occurred in Replicates 2 of Experiment 3, 1 of Experiment 5 and 1 of Experiment 8.

The effects of the significant interactions of NP, NK, and PK were varied in both the 1959 and 1960 experiments. A general interpretation of the interaction effects is as follows. A positive interaction in conjunction with nonsignificant or significant positive linear effects of the respective elements indicates a greater response to one or both of the elements at higher levels of the other. A positive interaction associated with significant negative linear terms indicates a smaller negative response to one or both of the elements at higher levels of the other. A negative interaction in conjunction with significant positive linear effects indicates a smaller response to one or both of the elements at

higher rates of the other. A negative interaction associated with significant negative linear effects indicates a further decrease in yield due to one or both of the elements at higher rates of the other.

The preceding description of the effects of applied N, P and K on percent leaf P indicates that the effects are varied and inconsistent, particularly with respect to the interactions. In general applied N and P increased the concentration of P in the corn leaf and K decreased it, but there were replicates and whole experiments where the opposite effect occurred.

5. Effect of evaluated uncontrolled variables on response of percent leaf P to applied N, P and K

In order to obtain information concerning which uncontrolled factors caused this variability the regression coefficients were related to the uncontrolled factors through simple correlation analysis as in previous sections. The relationships of the regression coefficients, describing the effect of applied N, P and K on percent leaf P, with the uncontrolled factors are shown in Table 37. The significant relationships indicate a change in value for the respective replicate regression coefficients as the uncontrolled factors varied in value.

These significant relationships were entered into a multiple regression equation as interactions in order to

Table 37. Simple correlation values^a showing the relationship of the regression coefficients, obtained from fitting a second degree polynomial to the leaf P percentage data from individual replicates, to selected uncontrolled factors

| Uncontrolled factor | Regression coefficient | | | | |
|---------------------|------------------------|---------------------|---------------------|---------------------|---------------------|
| | b ₁ | b ₂ | b ₃ | b ₄ | b ₅ |
| N _S | -0.174 | -0.056 | 0.077 | 0.009 | -0.084 |
| P _S | 0.162 | -0.332* | -0.126 | -0.064 | 0.147 |
| K _S | -0.162 | -0.182 ⁺ | 0.187 ⁺ | 0.221 ⁺ | 0.157 |
| pH | 0.092 | 0.149 | -0.073 | -0.146 | -0.164 |
| S | 0.227 ⁺ | -0.136 | -0.023 | -0.100 | 0.045 |
| T | 0.617** | 0.391 ⁺ | 0.076 | 0.359 ⁺ | -0.397 ⁺ |
| Y | 0.046 | -0.172 | 0.493* | 0.100 | -0.012 |
| D ₁ | 0.011 | -0.107 | -0.142 | -0.249 | -0.036 |
| D ₂ | 0.011 | 0.121 | 0.191 | -0.007 | -0.177 |
| D ₃ | 0.022 | 0.168 | 0.082 | 0.069 | -0.221 |
| | b ₆ | b ₇ | b ₈ | b ₉ | |
| N _S | -0.139 | 0.158 | -0.027 | 0.139 | |
| P _S | 0.131 | -0.138 | -0.143 | 0.119 | |
| K _S | -0.154 | -0.115 | -0.088 | 0.056 | |
| pH | -0.023 | 0.150 | 0.122 | 0.002 | |
| S | -0.081 | -0.136 | 0.062 | 0.212 ⁺ | |
| T | -0.030 | 0.087 | 0.243 | -0.316 ⁺ | |
| Y | -0.338 ⁺ | 0.517* | -0.254 | -0.210 | |
| D ₁ | 0.046 | 0.187 | 0.019 | 0.218 | |
| D ₂ | -0.115 | 0.463 ⁺⁺ | -0.309 ⁺ | -0.070 | |
| D ₃ | -0.131 | 0.255 | -0.058 | -0.011 | |

^aThe degrees of freedom were 34 for soil N, P and K, pH and stand. Since the other factors were imposed on both replicates at each location averages of the two regression coefficients were used and the degrees of freedom were 16.

obtain the flexibility necessary in describing percent leaf P obtained under the various experimental conditions. A total of 42 variates, including the check yield variates, those indicated in Table 37 and the variates from the regular second degree polynomial fitted to the individual replicate P percentages, were considered in the regression equation fitted to the 780 individual plot observations. Variates were eliminated from this final yield equation on the basis of a nonsignificant simple r-value relating the particular variate to total percent P or on the basis of a nonsignificant t-value for the regression coefficient in the final yield equation. The variates which were eliminated on the basis of a simple r-value were S^2 , $y \times P_S$, $K_S \times K$, $K_S \times N^2$ and $y \times K$. The variates which were deleted on the basis of the t-value were $K_S \times P$, $S \times PK$, $T \times P$ and $D_2 \times NP$. The amount of the total variation accounted for by the variates deleted on the basis of a t-value was nonsignificant according to a F-test.

The final equation which was considered to be adequate is shown in Table 38 with appropriate regression statistics. The coefficients of the applied variates were decoded, evaluated at zero input levels of the uncontrolled factors and transformed into bushels per acre per pound of input. This equation was highly significant at the 0.01 level of probability and attained an R^2 -value of 0.645. The coefficients of the K , P^2 , NK , PK , S and D_1 variates were not significant, but the variates were retained in the equation because they were included in interaction terms.

Table 38. Regression of all plot P percentages on observed and fertilizer variates and the correlation values of percent leaf P with each variate

| Variate | Equation $\hat{p} = b_0 + \sum b_i X_i^a$ | Probability level of coefficient | $r_{YX_i} \cdot x_j^b$ |
|---------------------------------|--|--|------------------------|
| | 0.31471 ^c | | |
| N | 0.07321 X_1 | + | 0.247** |
| P | 0.13057 X_2 | ** | 0.308** |
| K | -0.15828 X_3 | | -0.027 |
| N ² | -0.00035 X_4 | ** | -0.094* |
| P ² | 0.00008 X_5 | | -0.094* |
| K ² | 0.00175 X_6 | ++ | -0.056 ⁺ |
| NP | -0.00096 X_7 | ++ | 0.106** |
| NK | 0.00003 X_8 | | -0.051 ⁺ |
| PK | 0.00022 X_9 | | -0.059 ⁺ |
| S | -0.16752 X_{10} | | 0.038 ⁺ |
| N _S | 0.06180 X_{11} | ** | 0.088* |
| P _S | -1.91634 X_{12} | ** | 0.250** |
| K _S | -0.02958 X_{13} | ** | 0.099** |
| P _S x K _S | 0.00310 X_{14} | ** | 0.236** |
| pH | -1.23854 X_{15} | ** | 0.062++ |
| P _S x pH | 0.27404 X_{16} | ** | 0.256** |

^a $b_i \times 10^2$. $i = 1 \cdot \cdot \cdot 33$.

$b_{i,j} = 1 \cdot \cdot \cdot 33$. $i \neq j$.

^cThis is b_0 , the constant in the regression equation.

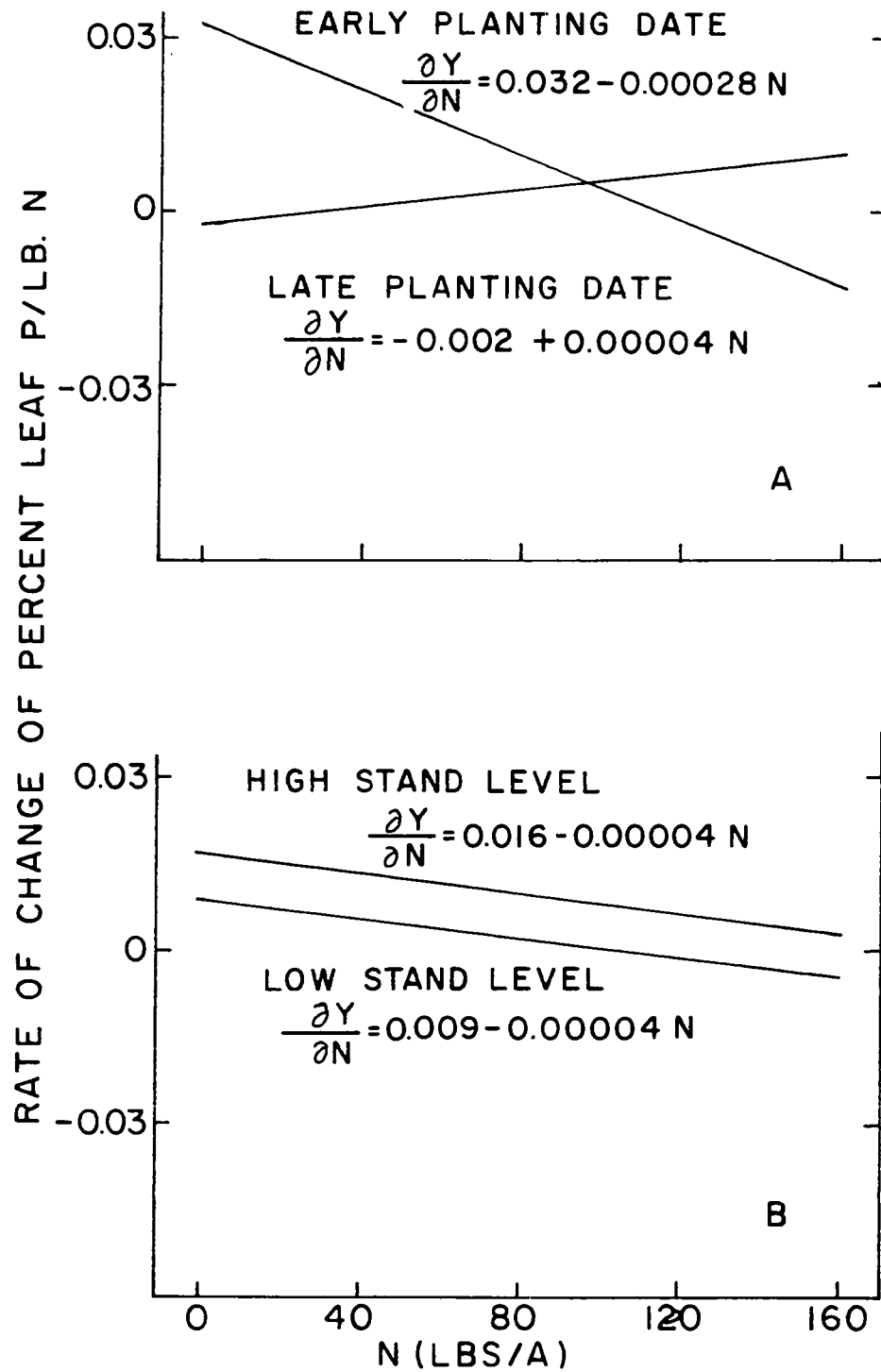
Table 38. (Continued)

| Variate | Equation $\hat{p} = b_0 + \sum b_i X_i^a$ | Probability level of coefficient | $r_{YX_i} \cdot x_j^b$ |
|---------------------------------|--|--|------------------------|
| W | -2.07409 X_{17} | ** | 0.235** |
| T | -0.04458 X_{18} | ** | -0.070 ⁺⁺ |
| Y | 0.31617 X_{19} | * | -0.104** |
| D ₁ | 0.03208 X_{20} | | 0.271** |
| D ₂ | 0.65378 X_{21} | ** | -0.168** |
| D ₃ | -0.14010 X_{22} | ** | -0.518** |
| D ₁ x D ₂ | -0.01546 X_{23} | ** | -0.437** |
| D ₂ x D ₃ | -0.03661 X_{24} | ** | -0.504** |
| P _S x P | -0.00342 X_{25} | ** | 0.173** |
| S x N | 0.00276 X_{26} | ** | 0.254** |
| T x N | -0.00036 X_{27} | * | 0.197** |
| T x N ² | 0.00001 X_{28} | ** | -0.094* |
| T x P ² | -0.00003 X_{29} | + | -0.114** |
| T x PK | -0.00002 X_{30} | + | -0.059 ⁺⁺ |
| Y x K ² | -0.00016 X_{31} | ++ | -0.073 ⁺⁺ |
| Y x NP | 0.00011 X_{32} | * | 0.111** |
| D ₂ x NK | -0.00001 X_{33} | + | 0.051 ⁺ |

The interaction terms involving controlled and uncontrolled factors from this yield equation of 33 variates show the effect of the uncontrolled factors on applied N and P, although the major quantitative effect of the uncontrolled factors was on the level of percent leaf P. The effect of applied N was dependent on stand level and time of planting as well as its interaction with applied P and K and the factors affecting these interactions. The effect of applied P depended on the amount of soil P and time of planting as well as its interactions with N and K and the factors affecting these interactions. The effect of applied K depended on the yield potential of the hybrid grown and on its interactions with applied N and P and the factors affecting these interactions. That the effects of applied N, P and K were not independent of each other or of the uncontrolled factors may be noted from the regression variates and their coefficients listed in Table 38.

The regression equation will be interpreted with respect to how the effects of applied plant nutrients varied as the uncontrolled factors varied in value. The effect of applied N on percent leaf P varied according to the time of planting as indicated by the negative $T \times N$ and positive $T \times N^2$ interactions. This effect is shown in Figure 14A where the rate of change of percent leaf P is plotted against rates of applied N. The early planting date occurred on April 30 and the late

Figure 14. Rate of change of percent leaf P with respect to applied N at two planting dates and two stand levels with all other factors at their average values



planting date occurred on June 7, a difference of 38 days. All other factors, controlled and uncontrolled, were held at average experimental values. Any point on the respective lines is a solution of the first partial derivative of the percent leaf P equation in Table 38 with respect to applied N. The general explanation and interpretation of this type of diagram was given in Section A, Part IV. This first partial derivative is a linear equation for any given time of planting.

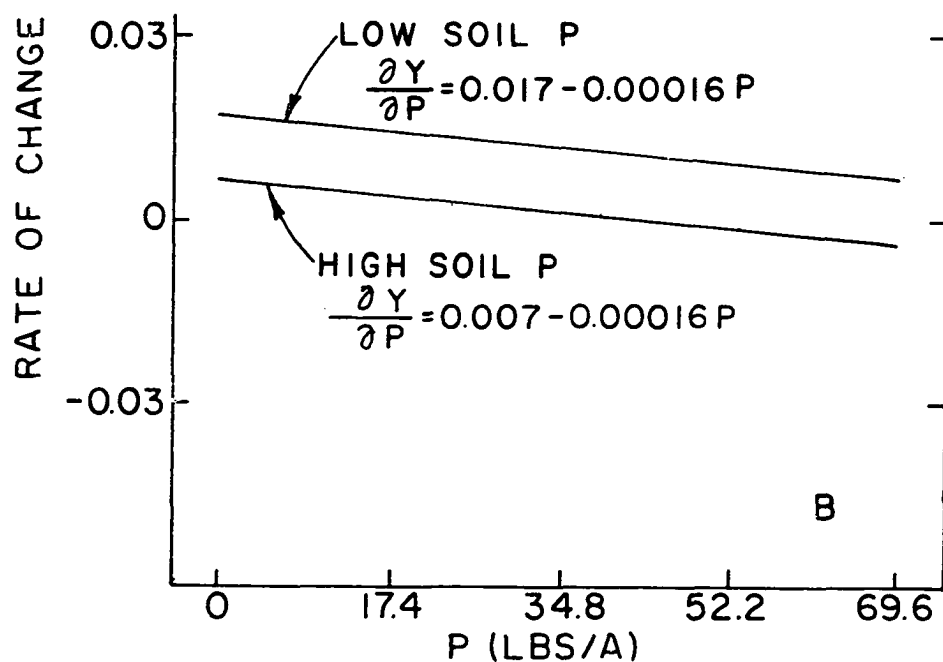
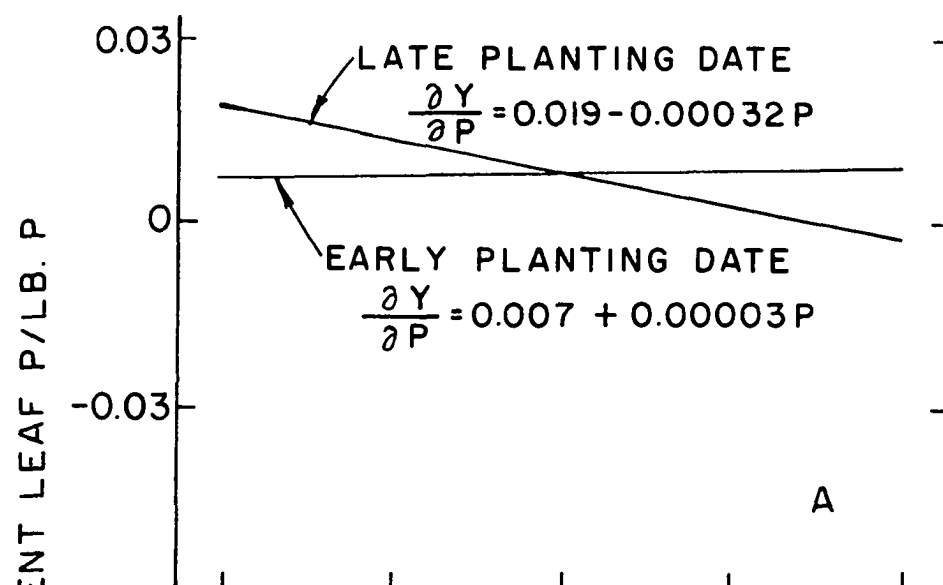
The effects portrayed in Figure 14A show that the initial effect of applied N is to increase leaf P concentration at an early planting date, whereas it decreases it initially at a late planting date. At the early planting date percent leaf P increased at a decreasing rate up to a maximum at 114 pounds of N per acre and then percent leaf P decreased from this maximum at higher rates of applied N per acre. At the late planting date percent leaf P decreased at a decreasing rate to a minimum at a rate of 50 pounds of N per acre and then percent leaf P increased. There are probably many effects confounded with the effect of time of planting on the change in percent leaf P due to applied N. The differential initial response of percent leaf P in this case may be due to temperature effects on root growth and dissolution of applied P. Also there may be a differential stimulation of root growth in rate and direction. The differential rate of change of percent leaf P at higher rates of applied N may be due to

entirely different processes. The reasons are not clear for this differential effect of applied N on percent leaf P, but this effect was present.

The effect of stand density on the change in percent leaf P due to applied N is indicated by the positive S x N interaction shown in Table 38. Figure 14B illustrates this effect for a low stand level of 10 thousand plants per acre and a high stand level of 17 thousand plants per acre. The initial increase in percent leaf P due to applied N was greater at a high stand level than at a low stand level, but the rate of decrease of the response was the same for both stand levels. This observed effect was probably due to a difference in the amount of dry matter produced rather than an increase in leaf P per plant. It is probable that the plants in a densely populated field were not as large as those in a planting of lower density. Therefore, the leaf P concentration would be higher in a high stand density situation.

The effect of time of planting on the change in percent leaf P due to applied P is indicated in Table 38 by the negative T x P² interaction. This effect, shown in Figure 15A, is opposite to that obtained with applied N. The early and late planting dates were the same as in Figure 14A. The initial increase in percent leaf P due to applied P was greater when corn was planted later, but the increase was at a decreasing rate. The increase in percent leaf P due to

Figure 15. Rate of change of percent leaf P with respect to applied P at two planting dates and two levels of soil P with all other factors at their average values



applied P was at a small increasing rate and appeared to increase at a near constant rate as applied P increased. The initial greater increase in percent leaf P due to applied P when corn was planted late rather than early may be due to availability and then subsequent differences in amount of dry matter produced.

Figure 15B which shows the rate of change of percent leaf P at two levels of soil P at different rates of applied P demonstrates that the initial response to applied P is greater at low levels of soil P. The rate of decrease of the response of percent leaf P to applied P was the same for both levels of soil P. Percent leaf P reached a maximum at 44 pounds of applied P per acre in the low soil P situation. Low soil P was 0.5 pounds per acre and high soil P was 18.4 pounds per acre. This appears to be a matter of soil P substituting for applied P in the increase of percent leaf P.

The effect of applied K on percent leaf P is indicated by the variates entailing K listed in Table 38. The effect of K was dependent on its interactions with N and P which were in turn dependent on the yield potential and occurrence of stress days in stress period 2. The mean effect of K in these experiments was small although consistent as indicated by the significant coefficients of the terms involving K. The application of K initially decreased percent leaf P, but percent leaf P increased at higher rates of K when all other

factors were at average experimental values. Although the above mentioned effects occurred, it is not apparent from these data why each effect occurred.

The effects of various levels of the uncontrolled factors on the change in percent leaf P due to applied fertilizer were not primarily on the differential response to applied N, P and K. The major quantitative effects of the uncontrolled factors were on the level of leaf P concentration. These effects of the various levels of the uncontrolled factors on percent leaf P obtained from applied N, P and K are illustrated in Figures 16 and 17 by predicted values of percent leaf P. The uncontrolled factors considered in these illustrations were soil N, P and K and the stress days which occurred in the 3 stress periods. Among these factors percent leaf P was affected only by the effect of soil P on applied P. The other uncontrolled factors were held at average experimental values as was applied K at the 41.6 pound per acre rate. The effect of applied K, although consistent, was not as large quantitatively as applied N and P.

Figure 16 illustrates percent leaf P as a function of applied N and P when soil N, P and K values are 46, 0.5 and 48 pounds per acre respectively. All other factors were at their average values, and the incidence of stress days in any period was zero for Figure 16 when considering the scale on the left ordinate. The effect of applied N and P was to

Figure 16. Predicted percent leaf P surface as a function of applied N and P with soil N, P and K at low observed values, zero incidence of stress days, high incidence of stress days and all other factors at their average observed values

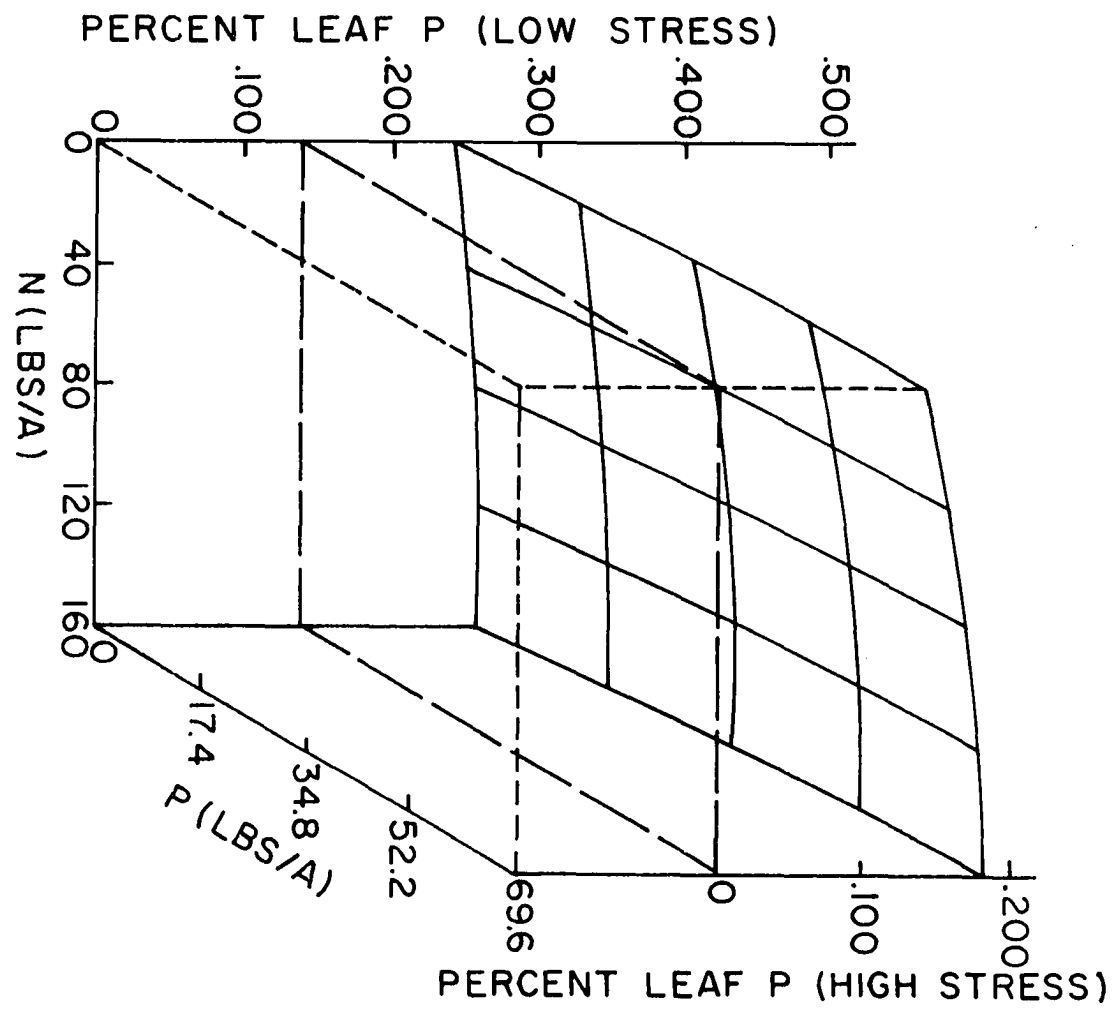
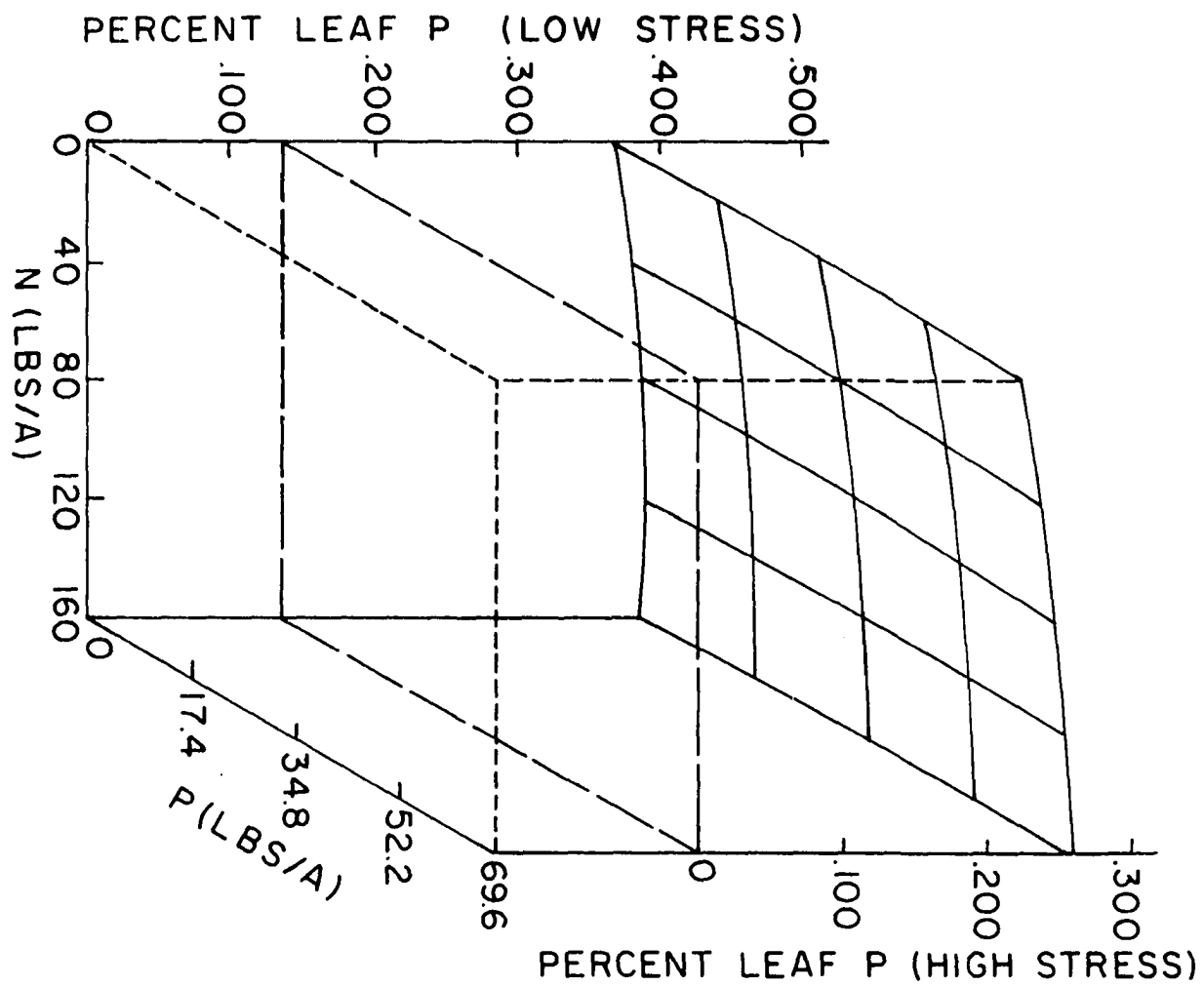


Figure 17. Predicted percent leaf P surface as a function of applied N and P with soil N, P and K at high observed values, zero incidence of stress days, high incidence of stress days, and all other factors at their average observed values



increase percent leaf P at a decreasing rate and the interaction of N and P was positive. The lowest percent leaf P value, 0.245, was predicted at zero pounds of N and zero pounds of P per acre. The highest percent leaf P value, 0.318, was predicted at 160 pounds of N and 69.6 pounds of P per acre.

The effect of a high incidence of stress days in all stress periods on percent leaf P with all other factors remaining the same as just previously described is also presented in Figure 16. The stress days occurring in stress periods 1, 2 and 3 were 20, 28, and 21 days respectively. The dashed line forms a new base and the scale is on the right ordinate. This shows the decrease in percent leaf P due to a high stress day incidence under the conditions specified for this figure. By subtracting 0.137 percent from the values predicted for a zero stress condition, the predicted values for a high stress day condition may be obtained. Since the shape of the surface was not changed, the lowest percent leaf P value, 0.108, and highest percent leaf P value, 0.181, were predicted at the same levels of applied N and P as under a zero stress day condition. It is obvious that the effect of weather as characterized by stress days was on the level of percent leaf P.

Figure 17 illustrates percent leaf P as a function of applied N and P at zero incidence of stress days and high

levels of soil N, P and K. These soil values were 109, 18.4 and 320 pounds per acre respectively. All other factor values were the same as in the previous figure. The percent leaf P scale on the left ordinate applies to this situation. The most noticeable characteristics are that percent leaf P is high over the entire surface and that the effect of applied P is very small. The effects of applied N and the interaction of N and P are the same as in the previous figure. The substitution effect of soil P for applied P is noticeable by the smaller linear response to applied P when compared with Figure 16. The lowest percent leaf P value, 0.363, was predicted at zero pounds of N and 69.6 pounds of P per acre.

The effect of a high incidence of stress days in all stress periods on percent leaf P with all other factors remaining the same as just previously described is also presented in Figure 17. The stress days occurring in stress periods 1, 2 and 3 were 20, 28 and 21 days respectively. The dashed line forms a new base and the scale is on the right ordinate. This shows the decrease in percent leaf P due to a high stress day incidence under the conditions specified for this figure. By subtracting 0.137 percent from the values predicted for a zero stress day condition the predicted values for a high stress day condition may be obtained. Since the shape of the surface was not changed, the lowest percent leaf P value, 0.226, and highest percent leaf P value, 0.264,

were predicted at the same levels of applied N and P as under a zero stress day condition. Again it can be seen that the effect of a high incidence of stress days is on the level of percent leaf P and not on the differential response to applied N and P.

The analyses and illustrations of the data indicate that the effect of weather and soil factors on the response to applied N, P and K was not as large quantitatively as the effect on the general level of percent leaf P. Figures 14B, 16 and 17 illustrate that soil P substitutes for applied P and the increase of percent leaf P due to applied P decreases as soil P increases. Figures 14A and 15A illustrate the effect of time of planting on the rate of change of percent leaf P as applied N and P were increased. The effect of weather on percent leaf P was on the general level of percent leaf P and not on the differential response to applied fertilizer. This effect is illustrated in Figures 16 and 17.

The general effect of high levels of soil factors was to increase the level of percent leaf P. The effect of a high incidence of stress days was to decrease the level of percent leaf P. The effect of the other uncontrolled factors on percent leaf P may be ascertained from Table 38 by the sign and value of the respective coefficients.

D. Concentration of K in Corn Leaves

The concentration of K in the corn leaf was affected by soil, weather, fertilizer, management and the interactions of

components of these factors. Factors affecting percent leaf K, other than applied fertilizer, were selected on the basis of their effect on leaf K percentages obtained with no fertilizer applied.

The same factors utilized previously in the analyses of percent leaf N and percent leaf P were considered in evaluating variations in percent leaf K due to applied N, P and K and uncontrolled factors. Values of the factors considered in this analysis and methods of characterization are presented in Section A dealing with corn yield. The factors affecting percent leaf K and the methods of selection are discussed in succeeding paragraphs.

1. Selection of soil variables

The soil variables were selected on the basis of simple correlations with check percent leaf K obtained from each replicate. The correlations of check percent leaf K with various soil test values are shown in Table 39. The only soil N measurement that was related to leaf K content was initial nitrate as shown by the positive correlation value. Nitrifiable N had no apparent affect on leaf K concentration.

Percent leaf K increased as the available P and exchangeable K increased. The measurements of soil K made on moist and dry samples were significantly correlated with leaf K percent at a 0.01 level of probability. The measurement made on moist samples were selected as the values for soil K

Table 39. Simple correlation values showing the relation of check percent leaf K to surface soil test values and to selected soil test variables by depth

| Soil test variable ^a | Depth in inches | | | | |
|---------------------------------|----------------------|---------|--------------------|---------|---------------------|
| | 0-6 | 6-12 | 12-18 | 18-24 | 24-36 |
| Initial nitrate | 0.258 ⁺ | 0.001 | 0.241 ⁺ | 0.517** | 0.360* |
| Nitrifiable N(d) | -0.160 | | | | |
| Nitrifiable N(m) | 0.118 | | | | |
| Available P(d) | 0.317 ⁺⁺ | 0.203 | 0.203 | 0.062 | 0.288 ⁺⁺ |
| Exchangeable K(d) | 0.644** | | | | |
| Exchangeable K(m) | 0.686** | 0.596** | 0.547** | 0.473** | 0.297 ⁺⁺ |
| pH | -0.298 ⁺⁺ | | | | |

^ad and m designations refer to measurements made on air dry and field moist samples respectively.

because of its slightly higher correlation value and it was used in previous analyses of yield and leaf chemical content. Check leaf K was also related to the subsoil measurements of initial nitrate and exchangeable K, but the surface soil test values reflected the amount of both soil factors in the remainder of each profile. A negative relationship between check percent leaf K and pH was obtained. This soil variable, initial nitrate, available P and exchangeable K were retained for further analyses.

2. Selection of variables other than soil

Other factors evaluated for their effect on check percent leaf K were stand (plant density), planting date, yield

Table 40. Simple correlation values relating check percent leaf K to stand, planting date, yield potential, wind damage factor and stress days in periods 1, 2 and 3

| | |
|-----------------|---------------------|
| Stand | 0.216 ⁺ |
| Planting date | 0.182 ⁺ |
| Yield potential | 0.370* |
| Wind damage | 0.019 |
| Stress period 1 | -0.392* |
| Stress period 2 | -0.134 |
| Stress period 3 | -0.212 ⁺ |

potential, wind damage and weather as characterized by stress days. The degree of correlation of check percent leaf K with these factors is shown in Table 40. Check leaf K was not related to the wind damage factor or stress days in stress period 2 as indicated by the nonsignificant correlation values.

Minor positive relationships with stand and planting date were obtained. A dilution effect was not obtained with stand indicating that soil K was available to the plants in adequate amounts. The effect of planting date, although small, may have been due to either the amounts of soil K present at a later planting date or due to a differential in top growth.

Check percent leaf K increased as yield potential increased. As the yielding ability of the corn hybrids increases, either the ability to take up or extract more K from

the soil increases. The effect of stress days in periods 1 and 3 was to decrease percent leaf K. This effect may be similar to that on check percent leaf P, i.e. it may be due to a decrease in soil solution and therefore the amount coming into solution is less. These significant variables were retained for further analyses.

3. Combined effect of uncontrolled variables on check percent leaf K

The purpose of the previous correlation analyses was to ascertain which variables accounted for variation in the check leaf K percentages. These variables and appropriate interactions were utilized in a multiple regression analysis to ascertain the amount of variation in check leaf K percentages accounted for by these variables. Indication of an interaction was obtained by graphical and covariance analysis as described in a previous section concerning corn yields.

Variables which had a significance at a probability level of 0.30 as determined by a t-test for the simple or multiple relationship were retained in the multiple regression equation. The multiple regression equation variates and values of the regression coefficients are presented in Table 41. This table also shows singular relationships of check percent leaf K with the variates through simple correlation values. An R^2 -value of 0.794 was obtained for this regression equation containing 15 variates. This regression mean square was significant at

Table 41. Regression of check percent leaf K on observed variates, significance level of regression coefficients and correlation values and their significance obtained from relating check percent leaf K to each variate

| Variate | Equation $\hat{k} = b_0 + \sum b_i x_i$ | Probability level of coefficient | $r_{yx_i} \cdot x_j^a$ |
|---------------------------------|--|--|------------------------|
| | 3.62017 ^b | | |
| NO ₃ | -0.08777 X ₁ | * | 0.258 ⁺ |
| P _S | -0.01701 X ₂ | | 0.317 ⁺⁺ |
| K _S | +0.00935 X ₃ | ** | 0.686** |
| P _S x K _S | -0.00056 X ₄ | * | 0.514** |
| pH | -0.34432 X ₅ | * | -0.298 ⁺⁺ |
| P _S x pH | +0.00880 X ₆ | | 0.305 ⁺⁺ |
| S | -0.00475 X ₇ | | 0.216 ⁺ |
| S ² | +0.00422 X ₈ | | 0.201 ⁺ |
| T | -0.01629 X ₉ | | 0.182 ⁺ |
| NO ₃ x T | +0.00063 X ₁₀ | + | 0.270 ⁺ |
| Y | -0.05781 X ₁₁ | | 0.370* |
| P _S x Y | -0.00004 X ₁₂ | | 0.343* |
| NO ₃ x Y | +0.00617 X ₁₃ | ++ | 0.265 ⁺ |
| D ₁ | -0.01452 X ₁₄ | | -0.392* |
| D ₃ | -0.01811 X ₁₅ | ++ | -0.212 ⁺ |

^a_{i,j} = 1 . . . 15. i ≠ j.

^bThis is b₀, the constant in the regression equation.

the 0.01 level of probability. This regression equation had several terms that attained significance at some level of probability in the equation although all of the variates had a significant singular relationship. The range of check leaf K was from 0.63 to 2.22 percent.

The value of these preliminary relationships is in elucidating factors which might affect either total percent leaf K or change in percent leaf K due to applied N, P and K and not in the equation itself.

4. Effect of applied N, P and K

The presence of treatment effect on leaf K percentages from each experiment was determined by a simple analysis of variance for each experiment. The analysis of variance for each 1959 experiment is presented in Table 42 and for each

Table 42. Analysis of variance of percent leaf K for each of six experiments conducted in 1959

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|----------------------|----------|
| | | 1 | 2 | 3 |
| Total | 37 | | | |
| Replicates | 1 | 0.0029 | 0.5690* | 0.4126** |
| Treatments | 18 | 0.0807** | 0.0938 | 0.1296** |
| Error | 18 | 0.0126 | 0.0987 | 0.0109 |
| | | 4 | 5 | 6 |
| Total | 37 | | | |
| Replicates | 1 | 0.0971** | 0.0008 | 0.4210** |
| Treatments | 18 | 0.0583** | 0.0940 ⁺⁺ | 0.0640** |
| Error | 18 | 0.0061 | 0.0493 | 0.0194 |

1960 experiment in Table 43.

Treatment effect attained a probability of 0.01 in 1959 Experiments 1, 3, 4 and 6, 0.10 in Experiment 5, but no effect occurred in Experiment 2. There is no apparent reason for the lack of treatment effect in Experiment 2. The error term is large, however, indicating that the effect of the treatments differed between replicates. Replicate differences were indicated in Experiments 2, 3, 4 and 6. Some of these differences can be attributed to differences in soil K between replicates but not in all experiments. Differences in soil K between replicates in these experiments ranged from 1 to 31 pounds per acre.

Treatment effect attained a probability level of 0.01 in 1960 Experiments 1, 3, 7 and 8, 0.05 in Experiments 2, 4 and 5, 0.10 in Experiment 5 and 0.30 in Experiments 6 and 11. No treatment effect occurred in Experiments 9 and 10 and the relatively high levels of soil K were apparently the reason for this. Experiment 9 also had a high incidence of drought days. Replicate differences are indicated in Experiments 1, 2, 5, 6, 8, 10 and 12. Most of these differences can be attributed to differences in amounts of soil K between replicates. The difference in soil K between replicates in these experiments ranged from 8 to 162 pounds per acre.

Stand may have had some influence on treatment effect and replicate differences. However, no adjustment for stand was

Table 43. Analysis of variance of percent leaf K for each of twelve experiments conducted in 1960

| Source of variation | Degrees of freedom | Mean squares for experiment | | |
|---------------------|--------------------|-----------------------------|----------------------|---------------------|
| | | 1 | 2 | 3 |
| Total | 45 | | | |
| Replicates | 1 | 0.0469 ⁺ | 0.4343** | 0.0057 |
| Treatments | 22 | 0.0776** | 0.0640* | 0.1470** |
| Error | 22 | 0.0266 | 0.0252 | 0.0454 |
| | | 4 | 5 | 6 |
| Total | 45 | | | |
| Replicates | 1 | 0.0122 | 1.6341** | 0.1996** |
| Treatments | 22 | 0.1121* | 0.0676 ⁺⁺ | 0.0276 ⁺ |
| Error | 22 | 0.0484 | 0.0373 | 0.0205 |
| | | 7 | 8 | 9 |
| Total | 45 | | | |
| Replicates | 1 | 0.0033 | 0.0986* | 0.0044 |
| Treatments | 22 | 0.0604** | 0.1079** | 0.0192 |
| Error | 22 | 0.0095 | 0.0162 | 0.0260 |
| | | 10 | 11 | 12 |
| Total | 45 | | | |
| Replicates | 1 | 0.8546** | 0.0033 | 0.3357** |
| Treatments | 22 | 0.0332 | 0.0475 ⁺ | 0.0420* |
| Error | 22 | 0.0306 | 0.0267 | 0.0165 |

made in these analysis of variance by experiment as stand is to be included in subsequent regression analysis as an independent variable.

The preceding analyses indicated different effects of treatments among experiments. A combined analysis of variance for the 1959 experiments shown in Table 44 does not

Table 44. Combined analysis of variance of percent leaf K for 1959 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|---------------------|
| Total | 227 | |
| Experiments | 5 | 3.9662** |
| Treatments/Experiments | 108 | 0.0867 |
| Treatments | 18 | 0.3412** |
| Treatments x Experiments | 90 | 0.0358 ^a |
| Replicates/Experiments | 6 | 0.2506 |
| Replicates | 1 | 0.0224 |
| Replicates x Experiments | 5 | 0.2962 |
| Error | 108 | 0.0328 |

^aPooled errors are heterogenous. The true significance value of the F-test for this variance comparison is nonsignificant on an individual experiment or combined basis.

indicate this. The pooled errors were heterogenous for 1959, but the treatments by experiments mean square was not significant under the assumption of homogeneous errors. The significance of the mean square for treatments and experiments

indicate that consistent differences due to treatments occurred and that the concentration of leaf K varied among experiments.

Table 45 shows the combined analysis of variance for the 1960 experiments. The problem of heterogeneity of pooled errors is again present. The treatments by experiments term is not significant at a single experiment's degrees of freedom of 22 and 22. However, it attains a probability of 0.05 if the pooled errors are homogeneous. The same conclusions may be drawn as in the 1959 experiments regarding the treatments and experiments terms.

Considerable evidence indicating response to treatments and difference in percent leaf K among experiments has been shown. A difference in the response to treatments among experiments may or may not have occurred. The treatment effect was due mainly to K, but N and P also had an effect. Multiple regression analysis was applied to percent leaf K, k , obtained from each replicate to ascertain these effects.

The regression statistics obtained from fitting the equation, $k = B_0 + B_1N + B_2P + B_3K + B_4N^2 + B_5P^2 + B_6K^2 + B_7NP + B_8NK + B_9PK$, to the data are shown in Table 46. In general the increase in concentration of K in the corn leaf was due to applied K. The effects of N and P are primarily those of dilution. Since the ultimate goal is to relate differences in responsiveness to specific uncontrolled factors through a

Table 45. Combined analysis of variance of percent leaf K for 1960 experiments

| Source of variation | Degrees of freedom | Mean square |
|--------------------------|--------------------|---------------------|
| Total | 551 | |
| Experiments | 11 | 4.2906** |
| Treatments/Experiments | 264 | 0.0672 |
| Treatments | 22 | 0.4092** |
| Treatments x Experiments | 242 | 0.0361 ^a |
| Replicates/Experiments | 12 | 0.3027 |
| Replicates | 1 | 0.1390 |
| Replicates x Experiments | 11 | 0.3176 |
| Error | 264 | 0.0274 |

^aPooled errors are heterogenous. Therefore, the true significance value of the F-test for the variance comparison cannot be ascertained. At 22 and 22 degrees of freedom it does not attain any significance level.

combined regression analysis, no attempt will be made at this point to explain why or why not a given response did or did not occur. However, the responses that did occur as indicated by being significant at the 0.30 level of probability or greater will be pointed out.

The effect of N in 1959 Experiments 3 and 5 and Replicate 1 of Experiment 6 was to decrease percent leaf K linearly. Applied N increased leaf K at an increasing rate in Replicate 1 of Experiment 1 as indicated by the positive

Table 46. Regression coefficients^a and R²-values obtained from fitting a second degree polynomial with interactions to the leaf K percentage data from each replicate of each experiment

| Replicate | Regression coefficient | 1959 Experiments | | |
|-----------|------------------------|-----------------------|----------------------|-----------------------|
| | | 1 | 2 | 3 |
| 1 | b ₀ | 1.6622 | 0.6270 | 1.1447 |
| | b ₁ | 0.0017** | 0.4565 | -0.0215 ⁺⁺ |
| | b ₂ | 0.0762* | -0.5605* | 0.5821 ⁺ |
| | b ₃ | 0.9653** | 1.1968** | 0.4347* |
| | b ₄ | 0.0010 ⁺ | -0.0015 | 0.0013 |
| | b ₅ | -0.0010 | 0.0030 | -0.0079 |
| | b ₆ | -0.0050 ⁺ | 0.0099 ⁺ | 0.0057 |
| | b ₇ | -0.0021 ⁺ | -0.0017 | -0.0051 ⁺ |
| | b ₈ | 0.0009 | -0.0030 | -0.0048 ⁺ |
| | b ₉ | -0.0025 | -0.0025 | -0.0004 |
| | R ² | 0.932 | 0.859 | 0.816 |
| 2 | b ₀ | 1.6718 | 1.0394 | 1.5871 |
| | b ₁ | -0.0418 | -0.9277 | -0.3808* |
| | b ₂ | -0.1285 | -0.4301 ⁺ | 0.1095 ⁺ |
| | b ₃ | 0.2711* | -1.0286 | 0.3296** |
| | b ₄ | -0.0004 | 0.0041 ⁺ | 0.0014 |
| | b ₅ | 0.0051 | 0.0119 | -0.0099 ⁺ |
| | b ₆ | -0.0050 | 0.0118 ⁺ | 0.0017 |
| | b ₇ | -0.0045 ⁺ | 0.0023 | 0.0000 |
| | b ₈ | 0.0052 | 0.0034 | -0.0011 |
| | b ₉ | 0.0037 | -0.0045 | 0.0074 ⁺ |
| | R ² | 0.799 | 0.580 | 0.849 |
| 1 | | 4 | 5 | 6 |
| | b ₀ | 0.7443 | 1.2360 | 1.5627 |
| | b ₁ | -1.0104 | -0.2947 ⁺ | -0.2763** |
| | b ₂ | 0.2332 | -0.6365 | 0.0724 |
| | b ₃ | 1.0028** | 1.6273 ⁺ | 0.9421** |
| | b ₄ | 0.0007 ⁺ | 0.0019 | 0.0000 |
| | b ₅ | -0.0012 | 0.0176 ⁺ | 0.0000 |
| | b ₆ | -0.0034 ⁺⁺ | -0.0067 | -0.0017 |

^avalues of b_i x 10². i = 1 . . . 9.

Table 46. (Continued)

| Replicate | Regression coefficient | 1959 Experiments | | |
|------------------|------------------------|-----------------------|-----------------------|-----------------------|
| | | 4 | 5 | 6 |
| 1 | b7 | -0.0004 | -0.0013 | 0.0034 ⁺ |
| | b8 | -0.0002 | -0.0054 ⁺ | -0.0011 |
| | b9 | -0.0037 ⁺⁺ | -0.0091 | -0.0081 ⁺⁺ |
| | R ² | 0.965 | 0.584 | 0.825 |
| 2 | b0 | 1.0290 | 1.6393 | 1.2546 |
| | b1 | -0.0946 | -0.3553 ⁺⁺ | -0.6384 |
| | b2 | -0.0087 ⁺ | -1.9440 ⁺⁺ | -0.1420 |
| | b3 | 0.7231 ^{**} | 1.2061 ^{**} | 1.2135 ^{**} |
| | b4 | 0.0014 ⁺⁺ | -0.0003 | 0.0028 [*] |
| | b5 | 0.0126 ^{**} | 0.0057 | -0.0039 |
| | b6 | -0.0042 ⁺ | -0.0082 ⁺⁺ | -0.0079 ⁺⁺ |
| | b7 | -0.0030 ⁺⁺ | 0.0090 ^{**} | 0.0036 ⁺ |
| | b8 | 0.0002 | -0.0011 | 0.0027 ⁺ |
| | b9 | 0.0041 | 0.0232 ⁺⁺ | 0.0083 |
| | R ² | 0.926 | 0.891 | 0.902 |
| 1960 Experiments | | | | |
| Replicate | Regression coefficient | 1 | 2 | 3 |
| | | | | |
| 1 | b0 | 1.7652 | 1.9154 | 1.5630 |
| | b1 | -0.2771 [*] | -0.3181 ⁺⁺ | -0.2340 ^{**} |
| | b2 | -0.0415 ⁺⁺ | -1.7150 ^{**} | -0.0465 ⁺ |
| | b3 | 0.3661 ^{**} | -0.0733 ^{**} | 0.7872 ⁺⁺ |
| | b4 | 0.0011 | 0.0010 | -0.0015 |
| | b5 | -0.0018 | 0.0162 [*] | 0.0096 |
| | b6 | -0.0022 | 0.0010 | -0.0089 ⁺ |
| | b7 | -0.0025 ⁺ | -0.0009 | -0.0030 |
| | b8 | 0.0014 | 0.0025 ⁺ | 0.0049 [*] |
| | b9 | 0.0036 ⁺ | 0.0067 ⁺⁺ | -0.0034 |
| | R ² | 0.746 | 0.810 | 0.735 |
| 2 | b0 | 1.7873 | 1.7170 | 1.5874 |
| | b1 | -0.0863 ⁺ | -0.1227 | -1.0024 ^{**} |
| | b2 | 0.7951 | -0.3099 | 0.2086 |
| | b3 | -1.0398 [*] | 0.3530 ^{**} | 1.1813 ^{**} |
| | b4 | 0.0000 | 0.0012 | 0.0043 [*] |
| | b5 | -0.0124 | 0.0051 | -0.0031 |
| | b6 | 0.0182 [*] | -0.0042 | -0.0117 ⁺⁺ |
| | b7 | 0.0003 | -0.0031 ⁺⁺ | -0.0015 |
| | b8 | -0.0006 | 0.0011 | 0.0021 ⁺ |

Table 46. (Continued)

| Replicate | Regression coefficients | 1960 Experiments | | |
|-----------|-------------------------|-----------------------|----------------------|-----------------------|
| | | 1 | 2 | 3 |
| 2 | b ₉ | -0.0012 | 0.0064 | 0.0043 ⁺ |
| | R ² | 0.518 | 0.659 | 0.822 |
| 1 | | 4 | 5 | 6 |
| | b ₀ | 1.8486 | 1.6713 | 2.0032 |
| | b ₁ | 0.2473 ⁺⁺ | -0.1991 ⁺ | -0.1166 ⁺ |
| | b ₂ | -1.1970 ⁺ | 0.1659 | 1.0995 ⁺ |
| | b ₃ | 0.5746* | -0.6909 ⁺ | -0.6830 |
| | b ₄ | -0.0022 ⁺ | 0.0004 | -0.0004 |
| | b ₅ | 0.0156 ⁺⁺ | 0.0045 | -0.0145 ⁺ |
| | b ₆ | -0.0021 | 0.0092 ⁺ | 0.0055 |
| | b ₇ | 0.0006 | -0.0034 ⁺ | -0.0003 |
| | b ₈ | -0.0007 | 0.0030 ⁺ | 0.0025 ⁺ |
| | b ₉ | -0.0024 | -0.0018 | 0.0025 |
| | R ² | 0.581 | 0.519 | 0.385 |
| 2 | b ₀ | 1.8201 | 1.1994 | 2.0121 |
| | b ₁ | -0.2941** | -0.0015* | -0.0134* |
| | b ₂ | 1.0379 | -0.2541 | 0.3491 ⁺ |
| | b ₃ | 0.2344* | 0.3572** | -0.3450* |
| | b ₄ | 0.0005 | -0.0008 | -0.0002 |
| | b ₅ | -0.0048 | 0.0056 | -0.0058 ⁺ |
| | b ₆ | 0.0027 | 0.0013 | 0.0054 ⁺⁺ |
| | b ₇ | -0.0057 ⁺⁺ | -0.0020 | 0.0024* |
| | b ₈ | -0.0005 | 0.0008 | 0.0011 ⁺ |
| | b ₉ | -0.0010 | -0.0026 | -0.0011 |
| | R ² | 0.732 | 0.681 | 0.691 |
| 1 | | 7 | 8 | 9 |
| | b ₀ | 1.4128 | 0.9154 | 1.6112 |
| | b ₁ | -0.3274 ⁺ | 0.2132** | 0.0088 |
| | b ₂ | -0.1039 | -0.0509 | -0.2304 ⁺⁺ |
| | b ₃ | 0.6961** | 0.3033** | 0.1788* |
| | b ₄ | 0.0019 ⁺⁺ | -0.0017* | -0.0002 |
| | b ₅ | 0.0037 | 0.0095* | -0.0012 |
| | b ₆ | -0.0061 ⁺ | 0.0041 ⁺ | 0.0000 |
| | b ₇ | -0.0010 | -0.0017 ⁺ | 0.0008 |
| | b ₈ | 0.0028* | 0.0007 | 0.0005 |
| | b ₉ | 0.0004 | 0.0000 | 0.0007 |
| | R ² | 0.779 | 0.933 | 0.472 |

Table 46. (Continued)

| Replicate | Regression coefficient | 1960 Experiments | | |
|-----------|------------------------|-----------------------|----------------------|----------------------|
| | | 7 | 8 | 9 |
| 2 | b ₀ | 1.3323 | 1.0223 | 1.6236 |
| | b ₁ | -0.0513* | -0.1140* | -0.4007 |
| | b ₂ | -0.3939 | -0.1382* | 0.7070 ⁺ |
| | b ₃ | 0.8317** | 1.0060** | -0.6564 |
| | b ₄ | -0.0001 | 0.0007 | 0.0022 ⁺ |
| | b ₅ | 0.0070 | 0.0036 | -0.0046 |
| | b ₆ | -0.0074 ⁺ | -0.0027 | 0.0063 ⁺ |
| | b ₇ | -0.0032 ⁺⁺ | -0.0030 ⁺ | -0.0019 ⁺ |
| | b ₈ | 0.0015 ⁺ | -0.0002 | 0.0033* |
| | b ₉ | 0.0164 | -0.0033 | -0.0016 |
| | R ² | 0.723 | 0.815 | 0.604 |
| 1 | | 10 | 11 | 12 |
| | b ₀ | 2.1729 | 1.8590 | 1.5608 |
| | b ₁ | -0.1146 ⁺ | -0.6148* | 0.0359** |
| | b ₂ | 1.1451 | -0.1423 ⁺ | -1.1886 |
| | b ₃ | 0.0812 ⁺⁺ | 1.1438** | 0.2641* |
| | b ₄ | 0.0015 | 0.0022 ⁺ | -0.0007 |
| | b ₅ | -0.0142 ⁺ | -0.0006 | 0.0100 ⁺ |
| | b ₆ | 0.0013 | -0.0091 ⁺ | 0.0001 |
| | b ₇ | -0.0016 | 0.0004 | -0.0018 ⁺ |
| | b ₈ | 0.0003 | 0.0021 ⁺ | -0.0006 |
| | R ² | 0.371 | 0.689 | 0.683 |
| 2 | b ₀ | 2.2310 | 1.8289 | 1.4018 |
| | b ₁ | -0.0530 | -0.5066 | -0.3512** |
| | b ₂ | -0.9520 | -0.0528 | 0.2465 |
| | b ₃ | 0.2766 | 1.2621 ⁺⁺ | 0.2755** |
| | b ₄ | -0.0001 | 0.0021 ⁺ | 0.0009 |
| | b ₅ | 0.0129 ⁺ | 0.0075 | -0.0003 |
| | b ₆ | -0.0023 | -0.0121* | -0.0011 |
| | b ₇ | 0.0003 | 0.0021 ⁺ | -0.0018 ⁺ |
| | b ₈ | 0.0008 | 0.0010 | 0.0018 ⁺ |
| | b ₉ | -0.0015 | -0.0046 ⁺ | -0.0022 |
| | R ² | 0.260 | 0.532 | 0.799 |

linear and quadratic coefficients. Percent leaf K was increased at higher rates of N as indicated by the positive quadratic coefficients in Experiment 4 and Replicates 1 of Experiment 2 and 2 of Experiment 6.

Applied P decreased percent leaf K linearly in Experiment 2 and Replicate 2 of Experiment 5. Leaf K was decreased at a decreasing rate by applied P in Replicate 2 of Experiment 4. Percent leaf K increased linearly due to applied P in Replicates 1 of Experiment 1 and 1 of Experiment 3, but at a decreasing rate in 2 of Experiment 3. Higher rates of P increased percent leaf K in Replicate 1 of Experiment 5.

An increase in percent leaf K resulted from applied K in Experiments 1, 3, 4, 5 and 6 and Replicate 1 of Experiment 2. This increase was at a decreasing rate in Experiment 4 and Replicates 1 of Experiment 1, 2 of Experiment 5 and 2 of Experiment 6, but was at an increasing rate in Replicate 1 of Experiment 2. Higher rates of K increased percent leaf K in Replicate 2 of Experiment 2.

The same trends were observed in the 1960 experiments. Applied N decreased percent leaf K in Experiments 1, 3, 5, 6 and 7 and in Replicates 1 of Experiment 2, 2 of Experiment 4, 2 of Experiment 8, 1 of Experiment 10, 1 of Experiment 11 and 2 of Experiment 12. This effect was at a decreasing rate in Replicates 2 of Experiment 3, 1 of Experiment 7, and 1 of Experiment 11. Percent leaf K was increased by applied N in

Replicates 1 of Experiment 4, 1 of Experiment 12 and at a decreasing rate in 1 of Experiment 8. Higher rates of N increased percent leaf K in Replicates 2 of Experiment 9 and 2 of Experiment 11. The effect of applied P was to decrease percent leaf K in 1960 Replicates 1 of Experiment 1, 1 of Experiment 3, 2 of Experiment 8, 1 of Experiment 9 and 1 of Experiment 11. A decrease at a decreasing rate was indicated in Replicates 1 of Experiment 2 and 1 of Experiment 4. An increase in leaf K concentration due to applied P was obtained in Replicate 2 of Experiment 9, and an increase at a decreasing rate was obtained in Experiment 6. Higher rates of applied P increased percent leaf K in Replicates 1 of Experiment 8, 2 of Experiment 10 and 1 of Experiment 12, but the opposite was indicated in Replicate 1 of Experiment 10. The effect of applied K was to increase percent leaf K in Experiments 3, 4, 7, 8, 11 and 12 and in Replicates 1 of Experiment 1, 2 of Experiment 2, 2 of Experiment 5, 1 of Experiment 9 and 1 of Experiment 10. The increase was at a decreasing rate in Experiments 3, 7, and 11, but at an increasing rate in Replicate 1 of Experiment 8. Leaf K concentration decreased at a decreasing rate due to applied K in Replicates 1 of Experiment 2, 1 of Experiment 5 and 2 of Experiment 6. A linear decrease was obtained in Replicate 1 of Experiment 2. Higher rates of K increased leaf K in Replicate 2 of Experiment 9.

The effects of the significant interactions of NP, NK and PK were different in both the 1959 and 1960 experiments. A general interpretation of the interaction effects is as follows. A positive interaction in conjunction with non-significant or significant positive linear effects of the respective elements indicates a greater response to one or both of the elements at higher levels of the other and a positive interaction associated with significant linear terms indicates a smaller negative response to one or both of the elements at higher levels of the other. If a negative interaction occurs in conjunction with significant positive linear effects, it indicates a smaller response to one or both of the elements at higher rates of the other. However, if a negative interaction is associated with significant negative linear effects, it indicates a further decrease in yield due to one or both of the elements at higher rates of the other.

The preceding description of the effects of applied N, P and K on percent leaf K indicates some inconsistency. In general applied K increased percent leaf K and N and P decreased it, but there were replicates where the opposite effect occurred.

5. Effect of evaluated uncontrolled variables on response of percent leaf K to applied N, P and K

In order to obtain information concerning which uncontrolled factors caused the variability in response to applied N, P and K the regression coefficients were related to the uncontrolled factors through simple correlation as in

previous sections. The relationship of the regression coefficients, describing the effect of applied N, P and K on percent leaf K, with the uncontrolled factors are shown in Table 47. The significant relationships indicate a change in value of the respective replicate regression coefficients as the uncontrolled factors varied in value.

These significant relationships were entered into a multiple regression equation as interactions in order to obtain the flexibility necessary in describing percent leaf K obtained under the various experimental conditions. A total of 42 variates, including the check leaf K variates, those indicated in Table 47 and the variates from the second degree polynomial fitted to the individual replicate K percentages were considered in the regression equation fitted to the 780 individual plot observations. Variates were eliminated from this final yield equation on the basis of a nonsignificant simple r -value relating the particular variate to total percent K or on the basis of a nonsignificant t -value for the regression coefficient in the final yield equation. The variates which were eliminated on the basis of a simple r -value were S^2 , $P_S \times P$, $K_S \times P$, $pH \times P$ and $D_1 \times PK$. The variates which were deleted on the basis of the t -value were K^2 , PK , $P_S \times pH$, $y \times P_S$, $NO_3 \times NK$, $P_S \times N^2$, $P_S \times P^2$, $P_S \times NK$, $pH \times NP$, $S \times N^2$, $D_1 \times N^2$, $D_3 \times NP$ and $D_3 \times PK$. The amount of the total variation accounted for

Table 47. Simple correlation values^a showing the relationship of the regression coefficients, obtained from fitting a second degree polynomial to the leaf K percentage data from individual replicates, to selected uncontrolled factors

| Uncontrolled factor | Regression coefficient | | | | |
|---------------------|------------------------|----------------------|---------------------|---------------------|----------------------|
| | b ₁ | b ₂ | b ₃ | b ₄ | b ₅ |
| NO ₃ | 0.141 | 0.174 | -0.204 | -0.149 | -0.116 |
| P _s | -0.314 ⁺⁺ | 0.300 ⁺⁺ | -0.114 | 0.209 ⁺ | -0.288 ⁺⁺ |
| K _s | -0.021 | 0.455 ^{**} | -0.406 [*] | -0.063 | -0.509 ^{**} |
| pH | -0.132 | -0.309 ⁺⁺ | 0.144 | -0.054 | 0.405 [*] |
| S | -0.157 | -0.167 | 0.001 | 0.181 ⁺ | 0.126 |
| T | 0.218 | -0.175 | 0.118 | -0.055 | 0.079 |
| Y | -0.138 | 0.175 | -0.048 | 0.048 | -0.143 |
| D ₁ | -0.035 | 0.115 | 0.230 | 0.340 ⁺ | -0.162 |
| D ₃ | 0.155 | -0.130 | -0.201 | 0.248 | 0.087 |
| | b ₆ | b ₇ | b ₈ | b ₉ | |
| NO ₃ | 0.045 | 0.072 | 0.231 ⁺ | 0.032 | |
| P _s | -0.060 | 0.073 | 0.337 [*] | 0.143 | |
| K _s | 0.206 | 0.109 | 0.147 | 0.022 | |
| pH | 0.055 | 0.205 ⁺ | -0.344 [*] | -0.147 | |
| S | 0.073 | 0.049 | -0.119 | -0.083 | |
| T | -0.205 | 0.080 | -0.032 | 0.017 | |
| Y | -0.107 | -0.104 | 0.177 | 0.258 | |
| D ₁ | -0.120 | -0.139 | -0.016 | 0.259 ⁺ | |
| D ₃ | 0.236 | -0.298 ⁺ | 0.083 | 0.450 ⁺⁺ | |

^aThe degrees of freedom were 34 for soil N, P and K, pH and stand. Since the other factors were imposed on both replicates at each location, averages of the two regression coefficients were used and the degrees of freedom were 16.

by the variates deleted on the basis of a t-value was non-significant according to a F-test.

The final equation which was considered to be adequate is shown in Table 48 with appropriate regression statistics. The coefficients of the applied variates were decoded, evaluated at zero input levels of the uncontrolled factors and transformed into bushels per acre per pound of input. This equation was highly significant at the 0.01 level of probability and attained an R^2 -value of 0.690. The coefficients of the P^2 and y variates were nonsignificant, but the variates were retained in the equation because they were included in interaction terms.

The interaction terms involving controlled and uncontrolled factors from this percent leaf K equation of 24 variates show the effect of the uncontrolled factors on applied N, P and K although the major quantitative effect of the uncontrolled factors was on the level of percent leaf K. The effect of applied N was dependent on the amount of soil P present as well as its interactions with P and K. The NK interaction was affected by soil pH. The effect of applied P depended on the amount of soil K present and level of soil pH as well as its interaction with applied N. The effect of applied K was dependent on the amount of soil K present as well as its interaction with applied N. That the effects of applied N, P and K were not independent of each other or of the uncontrolled factors may be noted from the regression

Table 48. Regression of all plot K percentages on observed and fertilizer variates and the correlation values of percent leaf K with each variate

| Variate | Equation $\hat{k} = b_0 + \sum b_i X_i^a$ | Probability level of coefficient | $r_{yx_i \cdot x_j}^b$ |
|---------------------------------|--|--|------------------------|
| | 1.88440 ^c | | |
| N | -0.64170 X_1 | ** | -0.150** |
| P | +1.52868 X_2 | ++ | -0.032 |
| K | -0.26615 X_3 | ** | 0.279** |
| N ² | +0.00307 X_4 | * | 0.089* |
| P ² | -0.02110 X_5 | | 0.080++ |
| NP | -0.00153 X_6 | ** | -0.102** |
| NK | +0.01003 X_7 | ++ | 0.057+ |
| S | +5.79471 X_8 | ** | 0.037+ |
| NO ₃ | -4.44861 X_9 | ** | 0.263** |
| P _S | +0.68657 X_{10} | ++ | 0.246** |
| K _S | +0.73750 X_{11} | ** | 0.652** |
| P _S x K _S | -0.02601 X_{12} | ** | 0.478** |
| pH | -22.23961 X_{13} | ** | -0.290** |
| T | -0.53902 X_{14} | + | 0.160** |
| Y | +0.82602 X_{15} | | 0.327** |
| T x NO ₃ | +0.02205 X_{16} | * | 0.237** |
| Y x NO ₃ | +0.33454 X_{17} | ** | 0.267** |
| D ₁ | -0.45689 X_{18} | ++ | -0.288** |
| D ₃ | -1.52871 X_{19} | ** | -0.249** |
| P _S x N | +0.00389 X_{20} | + | -0.101** |
| K _S x K | -0.00143 X_{21} | ** | 0.213** |
| K _S x P ² | -0.00004 X_{22} | + | 0.346** |
| pH x P ² | +0.00421 X_{23} | + | 0.056+ |
| pH x NK | -0.00134 X_{24} | ++ | 0.054+ |

^a $b_i \times 10^2$. $i = 1 \cdot \cdot \cdot 25$.

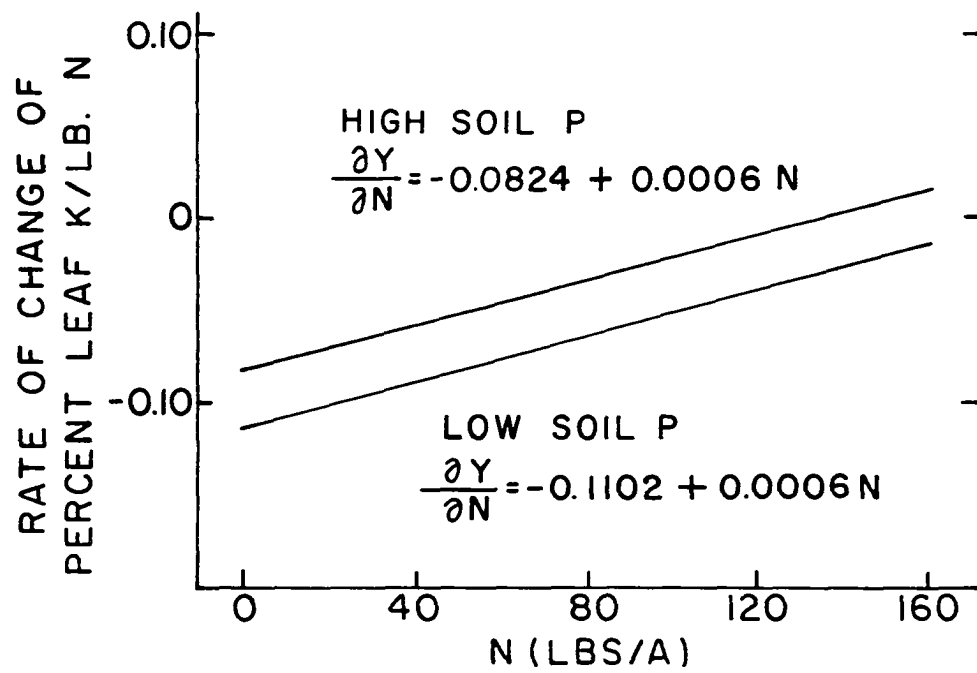
$b_i, j = 1 \cdot \cdot \cdot 25$. $i \neq j$.

^cThis is b_0 , the constant in the regression equation.

variates and their coefficients listed in Table 48.

The regression equation will be interpreted with respect to how the effects of applied plant nutrients varied as the uncontrolled factors varied in value. The effect of applied N on percent leaf K varied according to the amount of soil P present as indicated by the positive $P_s \times N$ interaction. This effect is shown in Figure 18 where the rate of change of percent leaf K is plotted against rates of applied N at two levels of soil P. High and low soil P were at 18.4 and 0.5 pounds per acre, respectively. All other factors, controlled and uncontrolled, were held at average experimental values. Any point on the respective lines is a solution of the first partial derivative of the percent leaf K equation in Table 48 with respect to applied N. The general explanation and interpretation of this type of diagram was given in Section A, Part IV. The effects illustrated in Figure 18 show that the initial effect of applied N is to decrease leaf K concentration at any level of soil P but decreases it more when soil P is low. The decrease in percent leaf K is at a decreasing rate in both cases. A minimum is reached at 137 pounds of applied N when the amount of soil P is 18.4 pounds per acre. The differential effect of applied N on percent leaf K due to the presence of large or small amounts of soil P cannot be explained on the basis of a difference in dry matter production.

Figure 18. Rate of change of percent leaf K with respect to applied N at two levels of soil P with all other factors at their average values

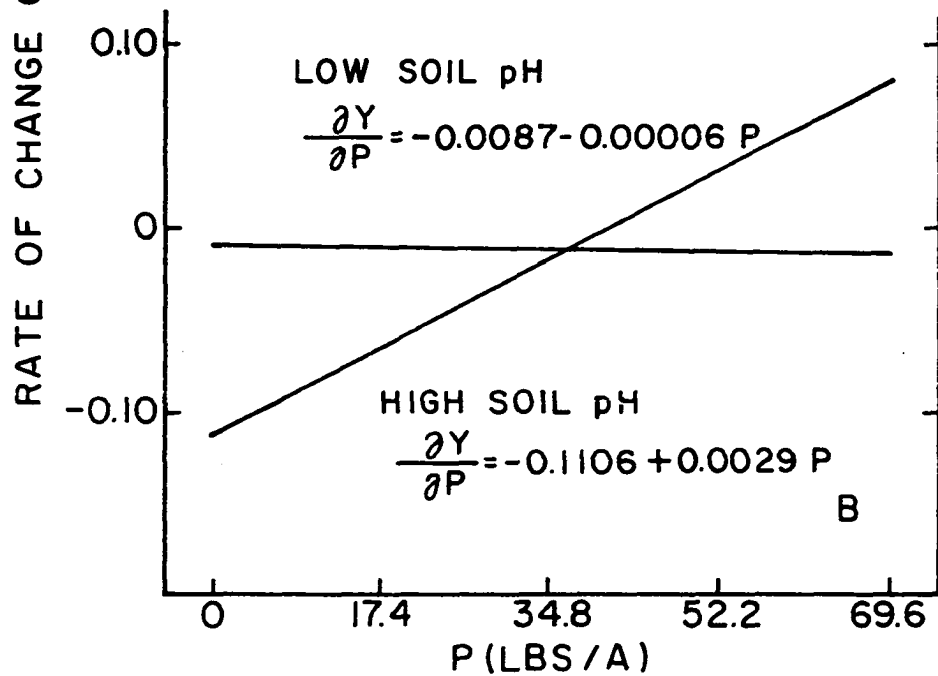
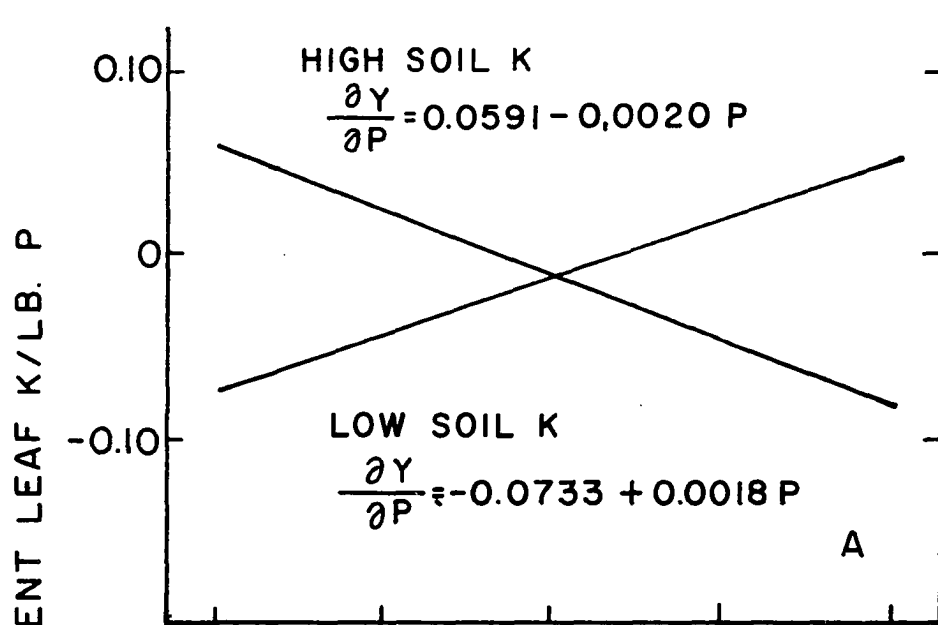


The effect of the amount of soil K present on the change in percent leaf K due to applied P is indicated by the negative $K_s \times P^2$ interaction listed in Table 48. Figure 19A illustrates this effect at high and low soil K of 320 and 48 pounds per acre respectively. Percent leaf K is increased at a decreasing rate due to applied P at a high level of soil K to a maximum at approximately 30 pounds of P. At a low level of soil K applied P decreases percent leaf K at a decreasing rate to a minimum at approximately 40 pounds of P. The differential effect of applied P on percent leaf K at different amounts of soil K may be partially due to a difference in dry matter produced.

pH also affected the change in percent leaf K due to applied P. This effect is illustrated in Figure 19B at two levels of soil pH, 6.1 and 8.1. Applied P decreased percent leaf K at a near constant small rate at the low soil pH. However, applied P decreased percent leaf K at a decreasing rate to a minimum at approximately 38 pounds of P when soil pH was high. This differential effect may have been due to the effect of pH on the availability of the applied P and consequently a differential in the effect of P on the physiological and growth processes of the plant.

The effect of applied K on percent leaf K was dependent on soil K and the interaction of N and K. The rate of change of percent leaf K with respect to applied K was positive

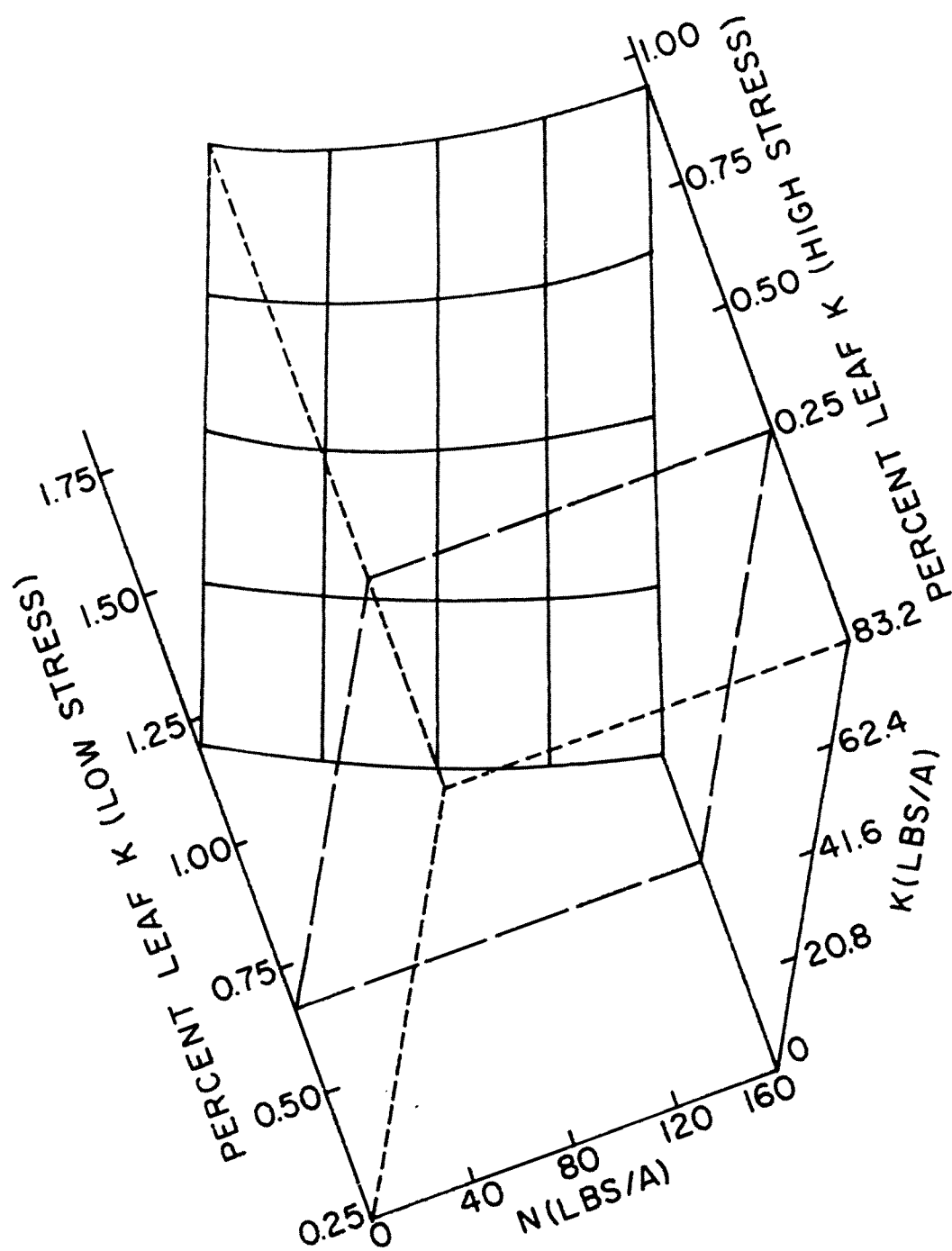
Figure 19. Rate of change of percent leaf K with respect to applied P at two levels of soil P and levels of soil pH with all other factors at their average values



and constant at any one level of soil K but was different between levels of soil K.

The effects of various levels of the uncontrolled factors on the change in percent leaf K due to applied fertilizer were not primarily on the differential response to applied N, P and K. The major quantitative effects of the uncontrolled factors were on the level of leaf K concentration. These effects of the various levels of the uncontrolled factors on percent leaf K obtained from applied N, P and K are illustrated in Figures 20, 21, 22 and 23 by predicted values of percent leaf K. The uncontrolled factors considered were initial soil NO_3 , soil P and K and the stress days in periods 1 and 3. The other uncontrolled factors were held at average experimental values. Figure 20 illustrates percent leaf K as a function of applied N and K when soil NO_3 , P and K values were 3, 0.5 and 48 pounds per acre, respectively. Applied P was held at a constant rate of 34.8 pounds per acre and the incidence of stress days was zero. The left vertical scale in this figure applies to this situation. The effect of applied N was to decrease percent leaf K at a decreasing rate, but applied K increased leaf K concentration at a constant rate. The interaction of N and K was positive. The lowest percent leaf K value, 1.14, was predicted at 160 pounds of N and zero pounds of K per acre. The highest percent leaf K value, 1.78, was predicted at zero

Figure 20. Predicted percent leaf K surface as a function of applied N and K with soil NO₃, P and K at low observed values, zero incidence of stress days, high incidence of stress days and all other factors at their average observed values

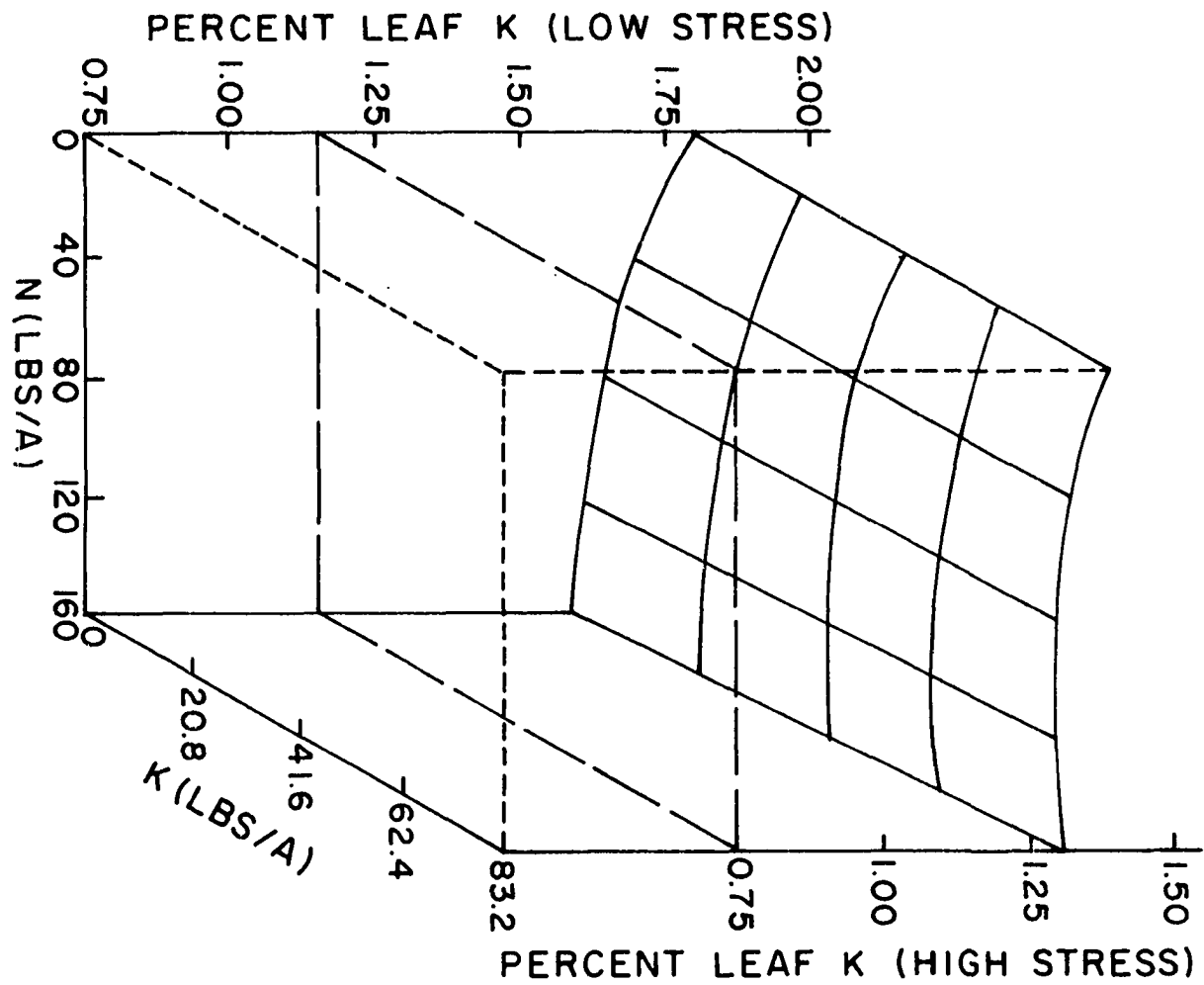


pounds of N and 83.2 pounds of K per acre.

The effect of a high incidence of stress days in stress periods 1 and 3 with all other factors remaining the same as just previously described is also presented in Figure 20. The stress days occurring in stress periods 1 and 3 were 20 and 21 respectively. The right vertical scale pertains to this situation with the dashed line forming a new base. This shows the decrease in percent leaf K due to a high stress day incidence under the conditions specified for this figure. By subtracting 0.41 percent from the values predicted for a zero stress day condition the predicted values for a high stress day condition may be obtained. Since the shape of the surface did not change the lowest percent leaf K value, 0.73, and highest percent leaf K value, 1.37, were predicted at the same levels of applied N and K as under a zero stress day condition. It is obvious that the effect of weather as characterized by stress days was on the level of percent leaf K.

Figure 21 illustrates percent leaf K as a function of applied N and K at high levels of soil NO_3 , P and K with applied P held constant at 34.8 pounds per acre. The soil values were 61, 18.4 and 320 pounds per acre. All other factor values were the same as in the previous figure. The effect of zero and high incidence of stress days is also portrayed in this figure with the left vertical scale pertaining to

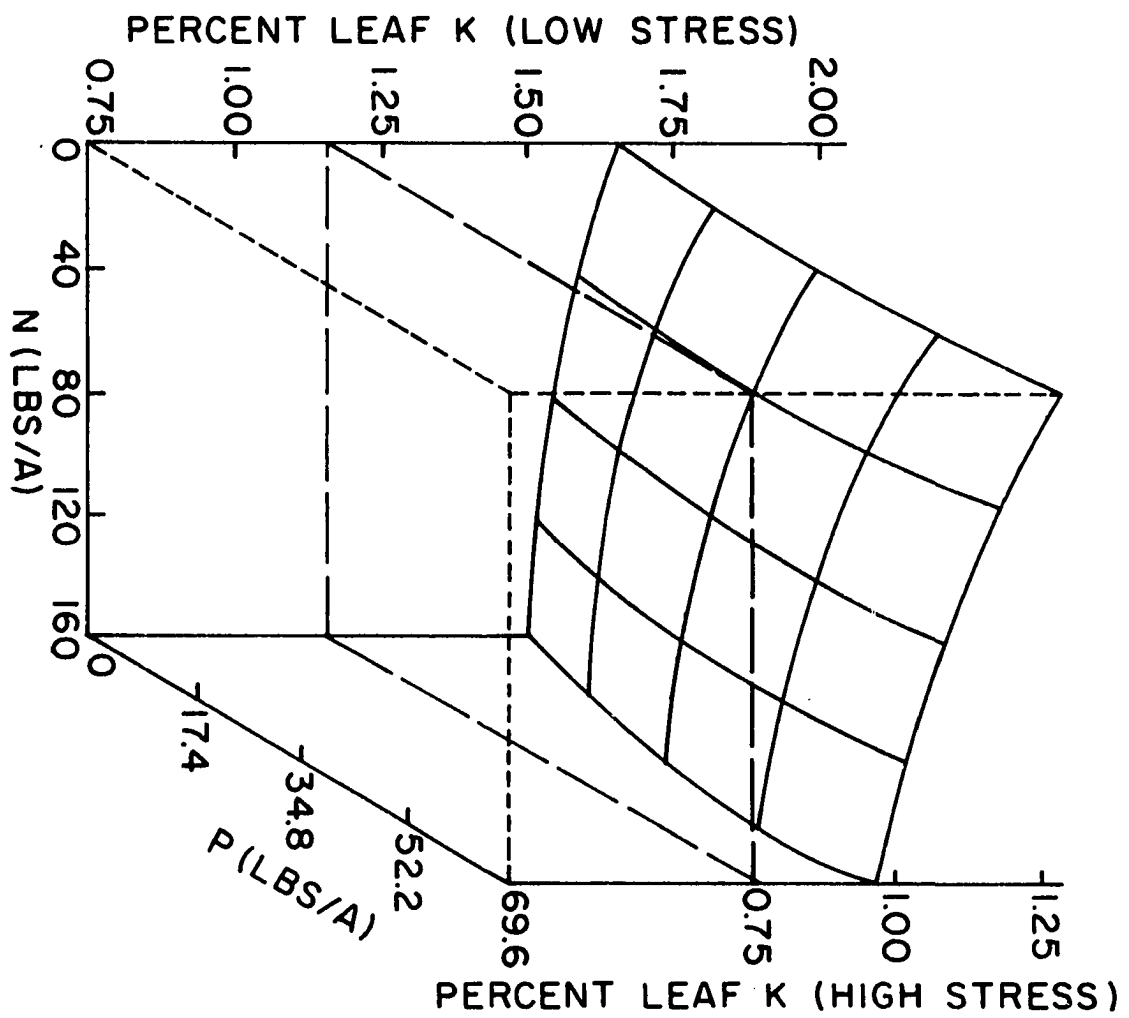
Figure 21. Predicted percent leaf K surface as a function of applied N and K with soil NO₃, P and K at high observed values, zero incidence of stress days, high incidence of stress days and all other factors at their average observed values



zero stress day incidence and the right vertical scale pertaining to high stress day incidence. The most noticeable characteristics when comparing Figure 21 with Figure 20 are that percent leaf K is higher over the surface, the decreasing effect of N is not as great and the increasing effect of K is not as great. The interaction of N and K is the same as in the previous figure. Soil K and soil P are responsible for the differential effect of applied K and N, respectively. It is an apparent substitution of soil K for applied K. Since the shape of the surface did not change due to an incidence of stress days, the high and low values of percent leaf K occurred at the same rates of applied N and K in spite of the occurrence of stress days. The lowest percent leaf K values, 1.58 and 1.17, were predicted at 160 pounds of N and zero pounds of K per acre, and the highest percent leaf K values, 1.79 and 1.58, were predicted at zero pounds of N and zero pounds of K per acre at low and high stress day incidence, respectively.

Figure 22 illustrates percent leaf K as a function of applied N and P at low levels of soil NO_3 , P and K with applied K held constant at 41.6 pounds per acre. The soil and other factor values were the same as for Figure 20. The effect of zero and high incidence of stress days is also portrayed in this figure with the left vertical scale pertaining to zero stress day incidence and the right vertical scale

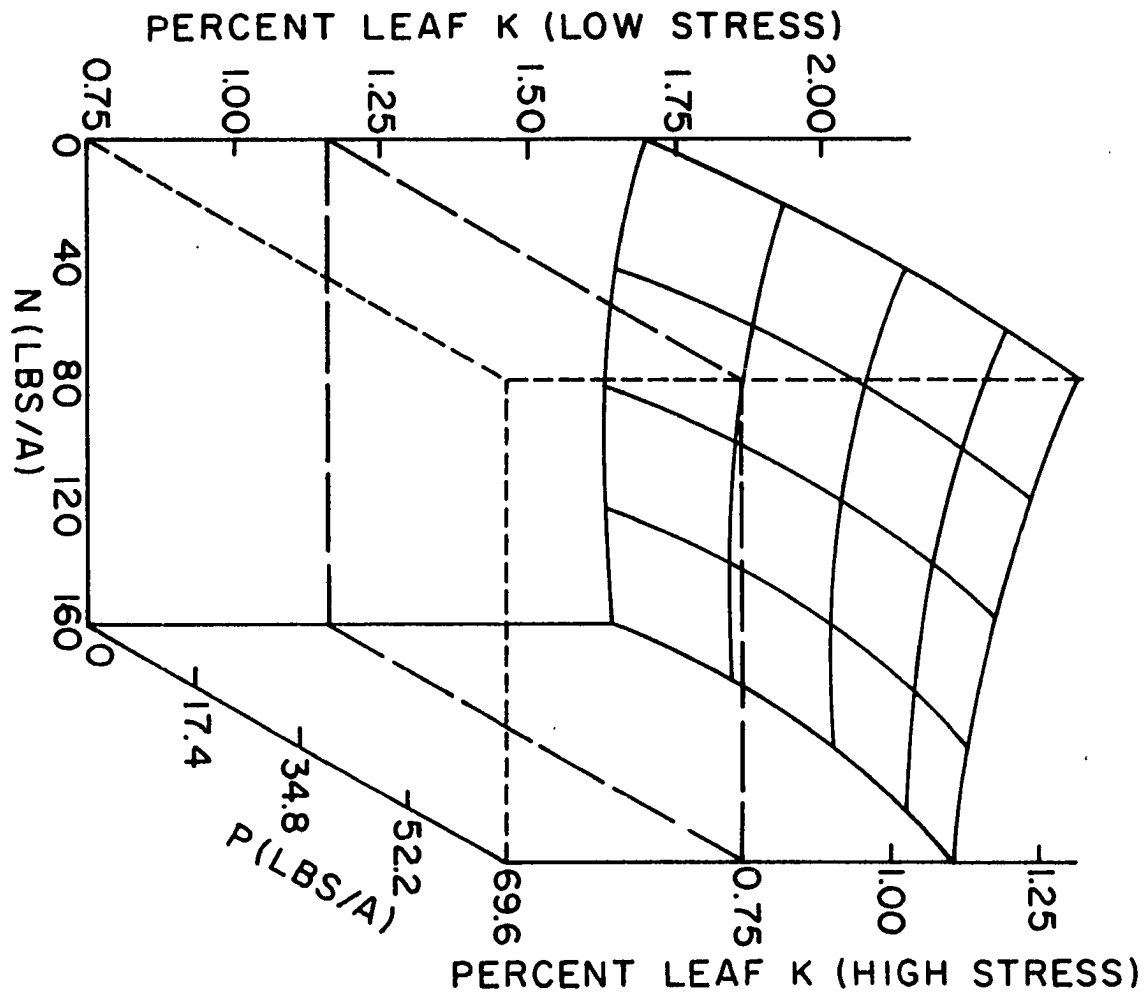
Figure 22. Predicted percent leaf K surface as a function of applied N and P with soil NO₃, P and K at low observed values, zero incidence of stress days, high incidence of stress days and all other factors at their average observed values



pertaining to high stress day incidence. Applied N and P decrease percent leaf K at a decreasing rate. The effect of a negative NP interaction is also noticeable. Since the effect of a high incidence of stress days in periods 1 and 3 of 20 and 21 days respectively is on the level of leaf K concentration and not on the shape of the surface, the predicted low and high values of percent leaf K occurred at the same rates for two stress day conditions. The lowest percent leaf K values, 1.36 and 0.95, were predicted at 160 pounds of N and 52.2 pounds of P per acre, and the highest percent leaf K values 1.70 and 1.29, were predicted at zero pounds of N and 69.6 pounds of P per acre at low and high stress day incidence, respectively.

Figure 23 illustrates percent leaf K as a function of applied N and P at high levels of soil NO_3 , P and K with applied K held constant at 41.6 pounds per acre. The soil and other factor values were the same as for Figure 21. The effect of zero and high incidence of stress days is also presented in this figure with the left vertical scale pertaining to zero stress day incidence and the right vertical scale pertaining to high stress day incidence. The most noticeable characteristics when comparing Figures 22 and 23 are that the level of percent leaf K is higher, the decreasing effect on percent leaf K by applied N is not as great and that applied P increases percent leaf K at a decreasing rate in Figure 23.

Figure 23. Predicted percent leaf K surface as a function of applied N and P with soil NO₃, P and K at high observed values, zero incidence of stress days, high incidence of stress days and all other factors at their average observed values



The effect of the NP interaction is the same in both figures. The differential effect of N and P in these figures is due to soil P and soil K, respectively. These effects were illustrated and discussed in Figures 18 and 19. Since the effect of a high incidence of stress days in periods 1 and 3 of 20 and 21 days respectively is on the level of leaf K concentration and not on the shape of the surface, the predicted low and high values of percent leaf K occurred at the same rates of applied N and P in spite of stress day occurrence. The lowest percent leaf K values, 1.52 and 1.11, were predicted at 160 pounds of N and 69.6 pounds of P per acre and the highest percent leaf K values, 1.78 and 1.37, were predicted at zero pounds of N and 34.8 pounds of P per acre at low and high stress day incidence, respectively.

The analyses and illustrations of the data indicate that the effect of weather and soil factors on the response to N, P and K was not as large quantitatively as the effect on the general level of percent leaf K. The effect of soil P on the rate of change in percent leaf K due to applied N is illustrated in Figure 18. Figure 19 illustrates the effect of soil K and pH on the rate of change of percent leaf K due to applied P. The percent leaf K surfaces in Figures 20, 21, 22 and 23 illustrate the effect of weather and soil factors on the general level of percent leaf K as well as to the differential response to the applied fertilizer caused by the

soil factors. It was quite evident that soil K substituted for applied K as illustrated in Figures 20 and 21.

The general effect of high levels of soil factors was to increase the level of percent leaf K. The effect of a high incidence of stress days was to decrease the leaf K concentration. The effect of the other uncontrolled factors on percent leaf K may be ascertained from Table 48 by the sign and value of the respective coefficients.

V. SUMMARY

The objectives of this study were to ascertain the effects of selected uncontrolled soil variables, management factors, and weather on the response of corn to applied N, P and K in multi-rate experiments. These variables were also studied as to their effect on plant composition as measured by N, P and K percent in the corn leaf.

Six multi-rate N-P-K experiments were conducted in 1959 and twelve in 1960 utilizing a central composite design to designate treatment combinations. The experimental sites were located on the Clarion, Nicollet and Webster soil series in central and north central Iowa. Requirements for the sites were second year corn, no fertilization since the previous year's crop, a soil test of low or very low for P or K and a uniform site as to slope and drainage.

The initial nutrient status of the soil was determined by soil test measurements of initial nitrate, nitrifiable N, available P, exchangeable K and pH. The management factors accounted for were planting date, corn hybrid (measured quantitatively by its ability to yield in the Iowa Corn Yield Test) and stand density. Moisture retention characteristics of the soils which were determined for each site were wilting point and field capacity. Available moisture capacity was determined from these two measurements. Daily precipitation was the only weather measurement made at the experimental

sites. Other measurements of weather were obtained from the weather station nearest to each experimental site.

The weather measurements and available soil moisture were integrated into one value by using a stress day criterion. A stress day was determined to be any day in which the available moisture was below 40 percent of the maximum available moisture capacity in the surface foot and in the root zone. The amount of available soil moisture for any day was computed by utilizing the amount of available moisture in the root zone, rainfall and depletion of soil moisture by estimating evapotranspiration. The stress days were accumulated into 4 continuous growing season periods which were 5, 4, 3 and 6 weeks in length and were designated as periods 1, 2, 3 and 4.

Yield was determined in bushels of grain per acre. Chemical analyses were made on corn leaves sampled at 75 percent silking. Concentration of N, P and K in the corn leaves was expressed in percent.

Selection of the uncontrolled factors, i.e. factors other than applied N, P and K, was made on the basis of the relation of check yield to these factors as determined by simple and multiple correlation. Variates describing the effect of applied N, P and K on yield were determined by multiple regression. A method was devised for determining the differential effect of applied N, P and K on yield caused by

the uncontrolled factors. The method was based on the assumption that the variates in a yield equation for each site or replicate adequately described the effects of applied N, P and K. The coefficients of these variates were related to the uncontrolled factors. A significant relationship indicated an interaction between the variate and uncontrolled factor. These indicated interactions were entered into a multiple regression equation that contained variates for the uncontrolled and controlled factors. The retention of the indicated interactions in the final equation was made on the basis of the significance attained by the coefficients of these interactions. The soil factors affecting check yield were nitrifiable N, available P, exchangeable K and pH. Management factors were time of planting, hybrid as measured by yield potential, and stand density. The weather factors were stress days in periods 1, 2 and 3. A wind damage factor was also included as 3 experiments were severely damaged by wind. A multiple regression equation of check yield as a function of the uncontrolled variates attained an R^2 -value of 0.823.

The effect of applied N, P and K was determined by individual experiment analysis of variance, combined analysis of variance for each year and multiple regression analysis for each replicate. The treatments affected yield in all experiments and the effect of the treatments varied among

experiments. It was also indicated that yields varied among experiments. The effect of N was to increase yields in 27 out of 36 replicates. The general effect of P and K was to increase yields but the effects were diverse. Significant effects of P and K were noted in 15 and 16 replicates respectively.

The effects of the uncontrolled factors on the change in yield due to applied N, P and K were determined by entering selected uncontrolled factors by applied fertilizer interaction variates into a yield equation containing uncontrolled factor variates and applied N, P and K variates. The final yield equation containing 30 variates had an R^2 -value of 0.599. The selection of the aforementioned interactions was determined by a method previously described. The effects of the uncontrolled factors on yield and response to N, P and K were illustrated.

The response to N alone was affected by the amount of soil N and soil K present, level of soil pH, time of planting, yield potential of the hybrid, and the number of stress days in stress period 1. The response to N was greater at a low level of soil N and it appeared that soil N substituted for applied N. Corn responded more to applied N initially at a high pH value, but the response at a high pH value decreased at a more rapid rate than that at a low pH value. The response to N was greater at an early planting date than at a

late planting date. The effect of a high incidence of stress days in stress period 1 was to increase the initial response to N, but the response decreased at a more rapid rate than that at a low incidence of stress days. The response to N increased as soil K increased but decreased as the yield potential of the hybrids increased. Although as the yield potential increased and the corn yield increased, the ability of the hybrid to utilize N in increasing yield decreased.

The effect of the uncontrolled factors on the response of corn to P and K was affected only as to their interaction with N. This may have been a consequence of the consistent responses to N and inconsistent responses to P and K. Stand affected the interaction of applied N by applied P. The NP interaction decreased as stand increased. This was probably a dilution effect caused by the increasing number of plants. The effect of soil P on the response to N was manifested only in its effect on the NK interaction. As soil P increased, the interaction of applied N by K became greater.

The analyses and illustrations of the corn yield data indicated that the effect of the uncontrolled factors on the response to applied N, P and K could be reduced to the examination of their effect on applied N alone. Although these results may have been specific to these experiments, it would simplify further experimentation and analyses by considering applied P and K and uncontrolled factors as to their effect

on the response of corn to N.

The analyses of the percent leaf N data were carried out in the same manner as those for the corn yield data. The soil factors affecting check percent leaf N were available P and exchangeable K. Nitrifiable N affected check percent leaf N only by its interactions with time of planting and the yield potential of the hybrids. Soil pH also affected check percent leaf N by its interaction with soil P. Management factors were time of planting and stand density. Yield potential was effective by its interactions with soil N and with soil P. The weather factors were stress days in stress periods 2 and 3. A wind damage factor was also added to account for variation due to a wind storm. A multiple regression equation of check percent leaf N as a function of the uncontrolled variates and interactions among these variates attained an R^2 -value of 0.660. This equation contained 17 variates.

The effect of applied N, P and K was indicated by individual analysis of variance, combined analysis of variance by year and multiple regression analysis for each replicate. The treatments affected percent leaf N in 17 out of 18 experiments. The combined analyses of variance indicated a difference in the effect of treatments on percent leaf N among experiments. It was also indicated that percent leaf N varied among experiments and that treatments affected

percent leaf N. The effect of N was to increase percent leaf N, but applied P and K decreased percent leaf N. The effects of P and K were diverse in the individual replicates.

The effects of the uncontrolled factors on the change in percent leaf N due to applied N, P and K were determined by multiple regression analysis. The interaction of the uncontrolled factors and controlled factors were entered as variates in a regression equation also containing uncontrolled factor variates and fertilizer variates. The percent leaf N regression equation, containing 25 variates, had an R^2 -value of 0.652.

The change in percent leaf N due to applied N was affected by soil N, soil K and stress days in stress period 2. The effect of soil N on the change in percent leaf N due to applied N appeared to be that of substitution. This effect was illustrated and it was noted that the initial response to applied N at a low level of soil N was greater than at a high level of soil N. The effect of soil K on the change in percent leaf N due to applied N was to decrease the effect of applied N. Low levels of soil K may have been a limiting factor at some experimental sites. A high incidence of stress days in stress period two affected the change in percent leaf N due to applied N by decreasing the positive response. The initial response to N at a low stress day incidence was higher than at a high stress day incidence. This

was probably due to greater availability of the N in a moist soil condition in the root zone.

The change in percent leaf N due to applied P was affected by soil N and stress days in stress period 2. These effects were illustrated. The initial effect of applied P on percent leaf N was negative. This negative effect lessened as soil N increased. The reason for this was not apparent from these data. The effect of an increasing stress day incidence was to decrease the effect of applied P on percent leaf N.

The effects of low and high levels of soil N, P and K and low and high incidence of stress days in periods 2 and 3 were illustrated. The general effect of high levels of soil factors was to increase the level of percent leaf N. The effect of a high incidence of stress days was to decrease the level of percent leaf N.

The analyses of the percent leaf P data were the same as for the corn yield and percent leaf N data. The soil factors affecting check percent leaf P were nitrifiable N, available P and exchangeable K. Soil pH affected check percent leaf P by its interaction with soil P. Management factors were time of planting, yield potential of the hybrids and stand density. The weather factors were stress days in periods 2 and 3. Stress days in period 1 affected check percent leaf P by their interaction with stress days in period

2. A multiple regression equation of check percent leaf P as a function of the uncontrolled variates and interactions among these variates attained an R^2 -value of 0.878. This equation contained 17 variates.

The effect of applied N, P and K was indicated by individual analysis of variance, combined analysis of variance by year and multiple regression analysis for each replicate. The treatments affected percent leaf P in 16 out of 18 experiments. The combined analyses of variance indicated a difference in the effect of treatments on percent leaf P among experiments and that the concentration of leaf P varied among experiments. The general effect of applied N was to increase percent leaf P. Applied P definitely increased the concentration of leaf P but the effect of applied K, although diverse, was to decrease percent leaf P.

The effects of the uncontrolled factors on the change in percent leaf P due to applied N, P and K were determined by multiple regression analysis. The interactions of the uncontrolled factors and controlled factors were entered as variates in a regression equation also containing uncontrolled factor variates and fertilizer variates. The percent leaf P regression equation, containing 33 variates, had an R^2 -value of 0.645.

The change in percent leaf P due to applied N alone was affected by stand density and time of planting. As stand

increased, percent leaf P increased due to applied N. This may have been due to the effect of other factors being limiting as stand density increased. The effect of time of planting on change in percent leaf P due to applied N was to increase percent leaf P initially at an early planting date of April 30, but percent leaf P was decreased initially at a late planting date of June 7. At the early planting date percent leaf P increased at a decreasing rate to a maximum, and at the late planting date it decreased at a decreasing rate to a minimum. This differential effect of applied N may have been due to a variety of factors such as temperature effects on root growth and dissolution of applied P. The differential effect at higher rates of applied N may have been due to entirely different reasons.

The change in percent leaf P due to applied P alone was affected by soil P and time of planting. As soil P increased the increase in percent leaf P due to applied P decreased. This appeared to be a substitution effect. As the planting date became later, percent leaf P initially increased more due to applied P when compared to an earlier planting date. This may have been due to availability of applied P and subsequent differences in amount of dry matter produced.

The general effect of applied K was to decrease percent leaf P. However this effect was small as the effect of K depended on its interaction with applied N and P, yield potent-

ial and the effect of stress days in period 2 on the NK interaction.

The effects of applied N and P as affected by the uncontrolled factors were illustrated. The effects of low and high levels of soil N, P and K and low and high incidence of stress days were also illustrated. The effect of these factors was larger quantitatively on the general level of percent leaf P than on the differential effect of applied N, P and K. High levels of soil factors increased percent leaf P. The effect of a high incidence of stress days was to decrease the level of percent leaf P.

The analyses of the percent leaf K data were the same as for the previous leaf nutrient concentration data. The soil factors affecting check percent leaf K were initial nitrate, available P, exchangeable K and pH. Management factors were time of planting, yield potential of the hybrids and stand density. The weather factors were stress days in periods 1 and 3. A multiple regression equation of check percent leaf K as a function of the uncontrolled variates and interactions among these variates attained an R^2 -value of 0.794. This equation contained 15 variates.

The effect of applied N, P and K was indicated by individual analysis of variance, combined analysis of variance by year and multiple regression analysis for each replicate. The treatments affected percent leaf K in 15 out of 18

experiments. The combined analyses of variance indicated a difference in percent leaf K among experiments and percent leaf K was affected by treatments. There was an indication of a differential effect due to treatments in the 1960 experiments but not in the 1959 experiments. The general effect of applied N and P was to decrease percent leaf K but this effect was quite diverse among experiments. The effect of applied K was to increase percent leaf K.

The effects of the uncontrolled factors on the change in percent leaf K due to applied N, P and K was determined by multiple regression analysis. The interactions of the uncontrolled factors and controlled factors were entered as variates in a regression equation also containing uncontrolled factor variates and fertilizer variates. The percent leaf K regression equation, containing 24 variates, had an R^2 -value of 0.690.

The change in percent leaf K due to applied N was affected by soil P. As soil P increased, the decrease in percent leaf K due to applied N decreased. The effect of N also depended on its interaction with applied P and K and the effect of soil pH on the NK interaction.

The change in percent leaf K due to applied P was affected by soil K and pH. As soil K increased the effect of applied P changed from that of decreasing percent leaf K at a decreasing rate to that of increasing leaf K at a

decreasing rate. There was not sufficient evidence to explain this on the basis of physiology or dry matter production. As soil pH increased in value from 6.1 to 8.1, the effect of applied P was to further decrease percent leaf K but at a decreasing rate. This may have been a matter of availability of P to the plant.

Applied K increased percent leaf K but as soil K increased the increase due to applied K decreased. This appeared to be a substitution effect. The effect of applied K also depended on applied N as was indicated by a NK interaction which in turn was affected by soil pH.

The effects of applied N, P and K as affected by the uncontrolled factors were illustrated. The effects of low and high levels of soil NO_3 , P and K and low and high incidence of stress days were also illustrated. The general effect of these factors was larger quantitatively on the level of percent leaf K than on the differential effect of applied N, P and K. High levels of soil factors increased percent leaf K. The effect of a high incidence of stress days was to decrease the level of percent leaf K.

The effects of the uncontrolled factors on the response of yield and percent leaf N, P and K to applied N, P and K differed greatly among these dependent variables. A larger differential effect of the response to the applied factors due to the uncontrolled factors was observed on grain yield.

This may indicate it is more of a problem of the utilization of applied N, P and K, as measured by grain yield, which is affected by the uncontrolled factors than the differential effect on plant uptake of applied N, P and K as measured by leaf composition.

The method of determining uncontrolled factor by controlled factor interactions by relating individual coefficients of yield equations from each replicate to the uncontrolled factors brought out many interactions which would have been difficult to ascertain by agronomic knowledge and logic. The degree of success of this method is difficult if not impossible to determine. It does depend on the effect of the various regression variates on yield and consequently their coefficients and on the degree of relation that is selected to determine whether the calculated relationship between a coefficient and an uncontrolled variable exists. It also depends on whether the indicated interaction is consistent and in the same direction over the range of experimentation.

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VIII. APPENDIX

Table 49. Cooperator, location and year of eighteen corn experiments

| Experi- ment number | Cooperator | County | Township | Section | Year |
|---------------------------|------------|-------------|--------------|---------|------|
| 1 | Fuller | Humboldt | Wacousta | 33 | 1959 |
| 2 | Korslund | Humboldt | Norway | 12 | 1959 |
| 3 | Thomason | Wright | Woolstock | 8 | 1959 |
| 4 | Webster | Cerro Gordo | Dougherty | 18 | 1959 |
| 5 | Clark | Cerro Gordo | Owen | 32 | 1959 |
| 6 | Newton | Blackhawk | Cedar | 7 | 1959 |
| 1 | Gugisberg | Humboldt | Lake | 1 | 1960 |
| 2 | Kellem | Humboldt | Norway | 26 | 1960 |
| 3 | Huddleston | Hamilton | Independence | 7 | 1960 |
| 4 | Olson | Hamilton | Ellsworth | 35 | 1960 |
| 5 | Boten | Hamilton | Scott | 25 | 1960 |
| 6 | Henderson | Story | Lincoln | 18 | 1960 |
| 7 | Carolus | Wright | Lincoln | 13 | 1960 |
| 8 | Hill | Wright | Blaine | 1 | 1960 |
| 9 | Nodland | Wright | Belmond | 14 | 1960 |
| 10 | Dunton | Cerro Gordo | Dougherty | 12 | 1960 |
| 11 | Crone | Hancock | Bingham | 15 | 1960 |
| 12 | Millar | Story | Indian Creek | 7 | 1960 |

Table 50. Soil test results for each experiment by replicate for each profile layer

| Year, ex- periment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|---|-----------------------|--------------------------------|---------------------|------|------|-------|------|------|
| | | pH | NO ₃ (M) | N(M) | N(D) | P (D) | K(M) | K(D) |
| <u>1959</u> | | | | | | | | |
| 1-1 | 0-6 | 6.35 | 4 | 74 | 83 | 1.5 | 93 | 118 |
| | 6-12 | 6.50 | 3 | 16 | 41 | 0.5 | 44 | 118 |
| | 12-18 | 6.80 | 12 | 12 | 21 | 0.5 | 58 | 152 |
| | 18-24 | 7.30 | 6 | 4 | 15 | 0.5 | 35 | 140 |
| | 24-36 | 8.10 | 3 | 4 | 9 | 0.5 | 25 | 114 |
| 1-2 | 0-6 | 6.40 | 3 | 76 | 85 | 1.4 | 88 | 130 |
| | 6-12 | 6.60 | 11 | 26 | 57 | 0.8 | 44 | 141 |
| | 12-18 | 7.00 | 14 | 12 | 18 | 0.5 | 43 | 171 |
| | 18-24 | 7.60 | 6 | 6 | 12 | 0.8 | 32 | 176 |
| | 24-36 | 8.20 | 3 | 4 | 12 | 0.8 | 25 | 142 |
| 2-1 | 0-6 | 6.70 | 26 | 67 | 103 | 4.6 | 72 | 157 |
| | 6-12 | 6.60 | 37 | 28 | 83 | 0.8 | 41 | 156 |
| | 12-18 | 7.10 | 12 | 13 | 33 | 0.8 | 32 | 168 |
| | 18-24 | 7.90 | 6 | 7 | 12 | 0.5 | 31 | 198 |
| | 24-36 | 8.20 | 11 | 3 | 9 | 0.5 | 32 | 155 |
| 2-2 | 0-6 | 7.80 | 8 | 107 | 142 | 4.1 | 70 | 154 |
| | 6-12 | 7.70 | 29 | 41 | 84 | 3.0 | 29 | 137 |
| | 12-18 | 7.80 | 6 | 15 | 33 | 0.8 | 24 | 162 |
| | 18-24 | 8.00 | 6 | 9 | 9 | 1.0 | 21 | 160 |
| | 24-36 | 8.20 | 6 | 4 | 6 | 0.8 | 23 | 167 |
| 3-1 | 0-6 | 6.65 | 4 | 65 | 89 | 2.5 | 83 | 122 |
| | 6-12 | 6.70 | 24 | 27 | 69 | 1.0 | 42 | 128 |
| | 12-18 | 6.80 | 15 | 13 | 15 | 1.5 | 33 | 169 |
| | 18-24 | 7.10 | 8 | 4 | 9 | 0.5 | 30 | 178 |
| | 24-36 | 8.10 | 3 | 3 | 6 | 0.5 | 32 | 184 |

^aSoil test results are given in pounds per acre as determined by the Iowa State University Soil Testing Laboratory. M designates determinations made at field moisture conditions, but results are correct to 25 percent soil moisture. D designates determinations made on air dry samples.

Table 50. (Continued)

| Year, experiment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|--------------------------------------|-----------------------|--------------------------------|---------------------|-------|-------|-------|-------|-------|
| | | pH | NO ₃ (M) | N (M) | N (D) | P (D) | K (M) | K (D) |
| 3-2 | 0-6 | 6.60 | 4 | 71 | 77 | 2.9 | 84 | 153 |
| | 6-12 | 6.70 | 4 | 34 | 68 | 1.5 | 44 | 156 |
| | 12-18 | 6.60 | 15 | 9 | 24 | 1.5 | 29 | 203 |
| | 18-24 | 6.80 | 6 | 4 | 12 | 0.5 | 21 | 215 |
| | 24-36 | 8.00 | 3 | 3 | 3 | 0.8 | 21 | 179 |
| 4-1 | 0-6 | 6.75 | 19 | 73 | 109 | 6.4 | 58 | 103 |
| | 6-12 | 7.00 | 4 | 25 | 68 | 1.8 | 24 | 88 |
| | 12-18 | 7.20 | 14 | 10 | 24 | 0.8 | 19 | 144 |
| | 18-24 | 7.60 | 6 | 3 | 12 | 0.5 | 17 | 129 |
| | 24-36 | 7.80 | 4 | 3 | 6 | 0.5 | 13 | 76 |
| 4-2 | 0-6 | 6.40 | 9 | 72 | 113 | 4.9 | 72 | 100 |
| | 6-12 | 6.50 | 4 | 26 | 85 | 1.5 | 24 | 104 |
| | 12-18 | 6.70 | 12 | 10 | 24 | 1.0 | 23 | 161 |
| | 18-24 | 6.90 | 3 | 3 | 12 | 0.5 | 23 | 157 |
| | 24-36 | 7.20 | 3 | 3 | 6 | 0.5 | 15 | 105 |
| 5-1 | 0-6 | 8.00 | 7 | 87 | 150 | 0.9 | 71 | 133 |
| | 6-12 | 8.10 | 24 | 24 | 91 | 1.0 | 24 | 111 |
| | 12-18 | 8.10 | 9 | 12 | 39 | 1.3 | 20 | 117 |
| | 18-24 | 8.10 | 6 | 9 | 27 | 1.0 | 23 | 131 |
| | 24-36 | 8.10 | 3 | 4 | 12 | 0.8 | 17 | 184 |
| 5-2 | 0-6 | 8.10 | 7 | 94 | 166 | 4.1 | 77 | 144 |
| | 6-12 | 8.10 | 3 | 23 | 76 | 1.0 | 33 | 139 |
| | 12-18 | 8.10 | 9 | 13 | 39 | 1.0 | 31 | 140 |
| | 18-24 | 8.10 | 5 | 9 | 24 | 0.5 | 24 | 158 |
| | 24-36 | 8.20 | 3 | 6 | 12 | 0.5 | 22 | 141 |
| 6-1 | 0-6 | 6.65 | 3 | 109 | 129 | 12.2 | 140 | 162 |
| | 6-12 | 6.40 | 19 | 49 | 95 | 4.5 | 59 | 144 |
| | 12-18 | 6.40 | 14 | 20 | 24 | 2.0 | 32 | 129 |
| | 18-24 | 6.40 | 6 | 10 | 15 | 1.5 | 27 | 124 |
| | 24-36 | 6.60 | 3 | 4 | 6 | 0.5 | 23 | 140 |
| 6-2 | 0-6 | 6.55 | 15 | 91 | 103 | 8.1 | 109 | 141 |
| | 6-12 | 6.40 | 31 | 43 | 71 | 3.0 | 50 | 126 |
| | 12-18 | 6.40 | 15 | 13 | 24 | 1.0 | 36 | 122 |
| | 18-24 | 6.40 | 9 | 6 | 12 | 1.0 | 27 | 78 |
| | 24-36 | 6.60 | 3 | 4 | 9 | 1.0 | 25 | 102 |

Table 50. (Continued)

| Year, ex- periment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|---|-----------------------|--------------------------------|---------------------|-------|-------|-------|-------|-------|
| | | pH | NO ₃ (M) | N (M) | N (D) | P (D) | K (M) | K (D) |
| <u>1960</u> | | | | | | | | |
| 1-1 | 0-6 | 6.50 | 33 | 74 | 103 | 4.2 | 84 | 169 |
| | 6-12 | 6.40 | 27 | 44 | 76 | 3.3 | 48 | 148 |
| | 12-18 | 7.30 | 15 | 23 | 39 | 1.8 | 27 | 156 |
| | 18-24 | 7.70 | 11 | 26 | 15 | 1.0 | 19 | 155 |
| | 24-36 | 7.90 | 11 | 14 | 12 | 0.5 | 19 | 156 |
| 1-2 | 0-6 | 6.40 | 41 | 69 | 107 | 3.5 | 134 | 185 |
| | 6-12 | 6.60 | 26 | 52 | 89 | 2.5 | 62 | 164 |
| | 12-18 | 7.30 | 16 | 25 | 33 | 0.8 | 40 | 162 |
| | 18-24 | 7.50 | 11 | 23 | 24 | 1.3 | 43 | 174 |
| | 24-36 | 7.90 | 11 | 15 | 12 | 0.5 | 37 | 136 |
| 2-1 | 0-6 | 7.00 | 29 | 72 | 109 | 2.9 | 94 | 201 |
| | 6-12 | 7.40 | 24 | 45 | 95 | 1.5 | 49 | 178 |
| | 12-18 | 7.60 | 13 | 23 | 36 | 1.0 | 36 | 182 |
| | 18-24 | 7.80 | 11 | 17 | 24 | 0.5 | 32 | 179 |
| | 24-36 | 8.00 | 8 | 13 | 20 | 0.5 | 29 | 160 |
| 2-2 | 0-6 | 6.35 | 46 | 72 | 93 | 2.4 | 125 | 188 |
| | 6-12 | 6.40 | 31 | 45 | 78 | 1.0 | 76 | 178 |
| | 12-18 | 6.40 | 19 | 23 | 24 | 1.0 | 50 | 172 |
| | 18-24 | 7.00 | 14 | 29 | 20 | 0.5 | 48 | 177 |
| | 24-36 | 7.70 | 11 | 14 | 12 | 0.5 | 45 | 181 |
| 3-1 | 0-6 | 6.70 | 28 | 53 | 76 | 15.2 | 113 | 138 |
| | 6-12 | 6.50 | 16 | 36 | 59 | 8.5 | 66 | 122 |
| | 12-18 | 6.20 | 10 | 11 | 12 | 3.3 | 39 | 120 |
| | 18-24 | 6.40 | 8 | 11 | 14 | 2.8 | 45 | 126 |
| | 24-36 | 6.40 | 10 | 12 | 12 | 2.5 | 42 | 122 |
| 3-2 | 0-6 | 6.60 | 33 | 46 | 78 | 17.2 | 107 | 143 |
| | 6-12 | 6.50 | 23 | 34 | 66 | 10.3 | 57 | 104 |
| | 12-18 | 6.20 | 13 | 14 | 21 | 3.0 | 41 | 118 |
| | 18-24 | 6.30 | 8 | 11 | 17 | 3.3 | 37 | 118 |
| | 24-36 | 6.40 | 5 | 14 | 12 | 3.8 | 38 | 118 |
| 4-1 | 0-6 | 7.40 | 42 | 61 | 121 | 3.7 | 124 | 213 |
| | 6-12 | 7.60 | 17 | 27 | 90 | 1.5 | 50 | 190 |
| | 12-18 | 7.70 | 12 | 23 | 33 | 1.0 | 31 | 185 |
| | 18-24 | 7.80 | 12 | 16 | 33 | 0.5 | 35 | 164 |
| | 24-36 | 7.90 | 8 | 16 | 32 | 0.5 | 32 | 187 |

Table 50. (Continued)

| Year, experiment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|--------------------------------|-----------------|--------------------------------|---------------------|-------|-------|-------|-------|-------|
| | | pH | NO ₃ (M) | N (M) | N (D) | P (D) | K (M) | K (D) |
| 4-2 | 0-6 | 7.75 | 26 | 63 | 101 | 1.0 | 144 | 232 |
| | 6-12 | 7.70 | 18 | 38 | 89 | 0.8 | 60 | 214 |
| | 12-18 | 7.80 | 12 | 24 | 29 | 0.8 | 33 | 208 |
| | 18-24 | 7.90 | 11 | 24 | 32 | 0.5 | 30 | 184 |
| | 24-36 | 8.00 | 8 | 15 | 23 | 0.5 | 24 | 190 |
| 5-1 | 0-6 | 6.25 | 32 | 59 | 119 | 11.0 | 134 | 182 |
| | 6-12 | 6.40 | 15 | 26 | 50 | 2.5 | 52 | 147 |
| | 12-18 | 6.40 | 12 | 20 | 21 | 1.0 | 39 | 145 |
| | 18-24 | 7.80 | 11 | 15 | 15 | 0.5 | 29 | 150 |
| | 24-36 | 7.90 | 8 | 12 | 11 | 0.5 | 31 | 148 |
| 5-2 | 0-6 | 6.75 | 24 | 60 | 103 | 3.9 | 80 | 142 |
| | 6-12 | 7.00 | 21 | 47 | 89 | 2.8 | 53 | 128 |
| | 12-18 | 7.60 | 12 | 23 | 24 | 1.3 | 35 | 134 |
| | 18-24 | 7.70 | 9 | 20 | 14 | 0.5 | 29 | 142 |
| | 24-36 | 8.00 | 6 | 13 | 12 | 0.5 | 24 | 110 |
| 6-1 | 0-6 | 6.25 | 44 | 60 | 99 | 6.9 | 254 | 238 |
| | 6-12 | 6.20 | 24 | 39 | 73 | 2.8 | 155 | 182 |
| | 12-18 | 6.20 | 12 | 20 | 17 | 0.8 | 88 | 158 |
| | 18-24 | 6.30 | 11 | 15 | 23 | 0.5 | 48 | 160 |
| | 24-36 | 6.50 | 8 | 15 | 17 | 0.5 | 41 | 156 |
| 6-2 | 0-6 | 6.20 | 53 | 70 | 118 | 10.5 | 282 | 256 |
| | 6-12 | 6.20 | 23 | 35 | 60 | 2.5 | 141 | 156 |
| | 12-18 | 6.10 | 12 | 17 | 23 | 1.0 | 57 | 140 |
| | 18-24 | 6.30 | 8 | 15 | 17 | 0.5 | 40 | 147 |
| | 24-36 | 6.50 | 12 | 11 | 15 | 0.5 | 24 | 147 |
| 7-1 | 0-6 | 6.20 | 44 | 71 | 111 | 3.0 | 110 | 174 |
| | 6-12 | 6.20 | 25 | 49 | 96 | 1.5 | 59 | 179 |
| | 12-18 | 6.50 | 12 | 23 | 30 | 1.0 | 46 | 171 |
| | 18-24 | 6.70 | 9 | 14 | 15 | 0.5 | 24 | 178 |
| | 24-36 | 6.80 | 6 | 12 | 12 | 0.5 | 20 | 180 |
| 7-2 | 0-6 | 6.10 | 44 | 75 | 121 | 2.5 | 104 | 169 |
| | 6-12 | 6.30 | 25 | 42 | 89 | 1.3 | 62 | 170 |
| | 12-18 | 6.40 | 16 | 24 | 36 | 1.0 | 46 | 164 |
| | 18-24 | 6.40 | 12 | 12 | 18 | 0.5 | 35 | 183 |
| | 24-36 | 7.00 | 6 | 8 | 12 | 0.5 | 36 | 182 |

Table 50. (Continued)

| Year, experiment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|--------------------------------|-----------------|--------------------------------|---------------------|-------|-------|-------|-------|-------|
| | | pH | NO ₃ (M) | N (M) | N (D) | P (D) | K (M) | K (D) |
| 8-1 | 0-6 | 7.75 | 61 | 73 | 162 | 0.5 | 48 | 117 |
| | 6-12 | 7.90 | 28 | 50 | 125 | 0.5 | 26 | 98 |
| | 12-18 | 8.00 | 11 | 23 | 39 | 0.5 | 20 | 90 |
| | 18-24 | 8.10 | 6 | 15 | 24 | 0.5 | 18 | 84 |
| | 24-36 | 8.10 | 6 | 17 | 24 | 0.5 | 16 | 84 |
| 8-2 | 0-6 | 7.70 | 58 | 87 | 160 | 3.0 | 56 | 125 |
| | 6-12 | 7.80 | 25 | 49 | 132 | 1.3 | 35 | 114 |
| | 12-18 | 8.00 | 12 | 21 | 53 | 0.8 | 22 | 112 |
| | 18-24 | 8.00 | 9 | 17 | 30 | 0.5 | 20 | 116 |
| | 24-36 | 8.10 | 6 | 12 | 23 | 0.5 | 20 | 102 |
| 9-1 | 0-6 | 6.55 | 52 | 88 | 115 | 12.1 | 158 | 182 |
| | 6-12 | 6.30 | 28 | 44 | 86 | 3.5 | 80 | 164 |
| | 12-18 | 6.30 | 17 | 24 | 30 | 2.6 | 59 | 170 |
| | 18-24 | 6.30 | 12 | 8 | 14 | 0.8 | 33 | 180 |
| | 24-36 | 6.60 | 6 | 6 | 12 | 0.5 | 26 | 156 |
| 9-2 | 0-6 | 6.60 | 54 | 77 | 136 | 18.4 | 145 | 182 |
| | 6-12 | 6.40 | 34 | 53 | 102 | 10.0 | 84 | 162 |
| | 12-18 | 6.40 | 22 | 28 | 32 | 2.8 | 43 | 156 |
| | 18-24 | 6.60 | 15 | 15 | 18 | 1.5 | 31 | 158 |
| | 24-36 | 7.20 | 20 | 14 | 15 | 0.5 | 24 | 166 |
| 10-1 | 0-6 | 6.45 | 49 | 78 | 135 | 14.5 | 320 | 296 |
| | 6-12 | 6.20 | 26 | 48 | 50 | 5.0 | 152 | 170 |
| | 12-18 | 6.00 | 12 | 18 | 17 | 2.0 | 78 | 120 |
| | 18-24 | 6.20 | 14 | 11 | 11 | 1.0 | 50 | 134 |
| | 24-36 | 6.10 | 12 | 9 | 12 | 5.8 | 38 | 120 |
| 10-2 | 0-6 | 6.60 | 34 | 72 | 108 | 7.5 | 158 | 176 |
| | 6-12 | 6.20 | 18 | 24 | 21 | 1.8 | 51 | 94 |
| | 12-18 | 6.00 | 12 | 11 | 12 | 1.0 | 31 | 102 |
| | 18-24 | 6.00 | 11 | 9 | 12 | 0.5 | 23 | 104 |
| | 24-36 | 6.20 | 11 | 11 | 14 | 1.8 | 20 | 92 |
| 11-1 | 0-6 | 6.10 | 57 | 78 | 124 | 9.5 | 122 | 146 |
| | 6-12 | 6.10 | 37 | 51 | 110 | 4.0 | 61 | 114 |
| | 12-18 | 6.10 | 23 | 24 | 24 | 1.8 | 36 | 118 |
| | 18-24 | 6.30 | 17 | 17 | 17 | 1.0 | 29 | 130 |
| | 24-36 | 6.40 | 12 | 11 | 12 | 0.5 | 27 | 110 |

Table 50. (Continued)

| Year, experiment and replicate | Depth in inches | Soil test results ^a | | | | | | |
|--------------------------------|-----------------|--------------------------------|---------------------|-------|-------|-------|-------|-------|
| | | pH | NO ₃ (M) | N (M) | N (D) | P (D) | K (M) | K (D) |
| 11-2 | 0-6 | 6.30 | 55 | 64 | 114 | 5.2 | 96 | 137 |
| | 6-12 | 6.30 | 37 | 45 | 77 | 3.3 | 59 | 120 |
| | 12-18 | 6.30 | 29 | 22 | 21 | 1.0 | 38 | 116 |
| | 18-24 | 6.80 | 17 | 12 | 17 | 0.5 | 31 | 138 |
| | 24-36 | 7.80 | 12 | 8 | 14 | 0.5 | 20 | 146 |
| 12-1 | 0-6 | 6.20 | 48 | 74 | 119 | 3.1 | 100 | 187 |
| | 6-12 | 6.50 | 24 | 24 | 53 | 1.0 | 31 | 154 |
| | 12-18 | 6.90 | 18 | 15 | 23 | 0.5 | 20 | 176 |
| | 18-24 | 7.40 | 14 | 9 | 17 | 0.5 | 18 | 146 |
| | 24-32 | 7.80 | 11 | 9 | 14 | 0.5 | 18 | 132 |
| 12-2 | 0-6 | 6.20 | 36 | 55 | 110 | 2.4 | 63 | 132 |
| | 6-12 | 6.40 | 21 | 31 | 33 | 0.5 | 28 | 116 |
| | 12-18 | 6.40 | 15 | 14 | 20 | 0.5 | 24 | 126 |
| | 18-24 | 5.90 | 13 | 10 | 15 | 0.5 | 25 | 142 |
| | 24-32 | 7.80 | 13 | 5 | 14 | 0.5 | 19 | 126 |

Table 51. Observed weekly precipitation in inches at experimental locations for eighteen weeks after planting date

| Week | 1959 Experiments | | | | | |
|------|------------------|------|------|------|------|------|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 5.10 | 0.38 | 0.60 | 3.30 | 2.96 | 0.72 |
| 2 | 3.58 | 0.35 | 0.76 | 0.00 | 3.97 | 0.00 |
| 3 | 0.00 | 0.72 | 2.75 | 0.10 | 0.00 | 0.00 |
| 4 | 0.00 | 3.05 | 0.00 | 0.00 | 0.00 | 0.25 |
| 5 | 0.15 | 0.00 | 0.00 | 2.89 | 0.03 | 2.37 |
| 6 | 0.40 | 0.00 | 0.00 | 0.22 | 1.87 | 0.70 |
| 7 | 2.40 | 0.00 | 5.10 | 0.26 | 1.60 | 1.70 |
| 8 | 0.62 | 4.10 | 0.00 | 0.10 | 0.24 | 0.00 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.36 | 0.21 |
| 10 | 0.00 | 0.00 | 0.00 | 1.48 | 0.00 | 1.58 |
| 11 | 2.10 | 0.00 | 0.00 | 0.43 | 0.97 | 0.22 |
| 12 | 0.00 | 0.20 | 1.35 | 0.16 | 0.12 | 1.95 |
| 13 | 1.70 | 1.70 | 0.70 | 3.68 | 0.40 | 0.07 |
| 14 | 3.05 | 0.17 | 0.00 | 0.66 | 2.93 | 0.08 |
| 15 | 0.00 | 0.00 | 4.84 | 1.69 | 1.16 | 0.85 |
| 16 | 0.20 | 4.89 | 0.53 | 0.00 | 1.75 | 0.04 |
| 17 | 0.00 | 0.74 | 0.00 | 2.30 | 0.00 | 0.52 |
| 18 | 1.12 | 0.00 | 0.25 | 1.74 | 0.63 | 3.54 |

Table 51. (Continued)

| Week | 1960 Experiments | | | | | |
|------|------------------|------|------|------|------|------|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1.24 | 1.23 | 0.42 | 2.09 | 1.06 | 1.25 |
| 2 | 0.34 | 0.18 | 1.28 | 0.38 | 1.14 | 1.39 |
| 3 | 4.11 | 0.37 | 2.23 | 1.40 | 0.26 | 0.21 |
| 4 | 0.19 | 0.98 | 1.50 | 1.10 | 2.11 | 0.90 |
| 5 | 0.00 | 0.00 | 0.07 | 0.00 | 0.77 | 1.25 |
| 6 | 1.06 | 0.00 | 0.16 | 0.38 | 0.26 | 0.12 |
| 7 | 0.77 | 0.30 | 1.04 | 3.60 | 0.32 | 0.16 |
| 8 | 0.61 | 0.70 | 0.78 | 0.72 | 1.43 | 1.75 |
| 9 | 0.02 | 0.00 | 0.34 | 1.91 | 0.66 | 0.00 |
| 10 | 0.82 | 0.00 | 0.00 | 0.00 | 0.12 | 0.82 |
| 11 | 0.06 | 0.70 | 1.96 | 1.50 | 0.31 | 0.00 |
| 12 | 0.08 | 0.25 | 0.00 | 0.00 | 1.10 | 0.87 |
| 13 | 0.00 | 1.70 | 0.30 | 2.40 | 0.00 | 0.06 |
| 14 | 0.55 | 1.25 | 0.20 | 3.02 | 2.16 | 3.14 |
| 15 | 0.48 | 0.00 | 0.77 | 0.00 | 2.51 | 1.91 |
| 16 | 0.44 | 0.10 | 1.75 | 0.00 | 0.00 | 0.00 |
| 17 | 2.01 | 2.00 | 2.52 | 1.90 | 0.25 | 0.26 |
| 18 | 0.00 | 2.30 | 1.92 | 1.51 | 1.96 | 1.38 |

Table 51. (Continued)

| Week | 1960 Experiments | | | | | |
|------|------------------|------|------|------|------|------|
| | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 0.01 | 1.07 | 0.00 | 0.00 | 0.00 | 0.50 |
| 2 | 0.14 | 0.00 | 0.50 | 0.16 | 0.06 | 0.66 |
| 3 | 0.78 | 0.00 | 1.02 | 1.88 | 2.85 | 0.00 |
| 4 | 0.30 | 0.52 | 0.86 | 1.50 | 0.48 | 1.80 |
| 5 | 0.40 | 0.36 | 0.95 | 0.20 | 0.10 | 3.12 |
| 6 | 0.57 | 0.16 | 0.45 | 0.39 | 0.20 | 0.04 |
| 7 | 0.10 | 0.00 | 0.12 | 0.00 | 0.35 | 0.75 |
| 8 | 0.00 | 0.47 | 0.07 | 0.68 | 0.30 | 0.00 |
| 9 | 0.26 | 0.04 | 0.07 | 0.64 | 0.15 | 0.58 |
| 10 | 0.26 | 0.44 | 0.89 | 1.11 | 0.30 | 0.00 |
| 11 | 0.80 | 0.00 | 0.69 | 2.10 | 0.30 | 1.82 |
| 12 | 1.60 | 1.20 | 1.28 | 3.80 | 1.40 | 1.46 |
| 13 | 0.40 | 1.64 | 0.18 | 2.09 | 2.00 | 0.00 |
| 14 | 1.75 | 0.22 | 1.73 | 0.00 | 0.00 | 0.00 |
| 15 | 0.03 | 1.70 | 0.06 | 0.00 | 0.00 | 0.00 |
| 16 | 1.30 | 0.00 | 1.03 | 1.25 | 0.00 | 2.00 |
| 17 | 3.00 | 0.00 | 1.60 | 3.07 | 3.27 | 0.30 |
| 18 | 0.00 | 1.97 | 0.00 | 0.33 | 0.12 | 0.00 |

Table 52. Soil moisture holding characteristics and available moisture^a in inches at planting time by depth for each experiment conducted in 1959 and 1960

| Depth in feet | 1959 | | | | | | | |
|---------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|
| | Experiment 1 | | | Field available moisture | Experiment 2 | | | Field available moisture |
| | Field capac- ity | Wilt- ing point | Available moisture capacity | | Field capac- ity | Wilt- ing point | Available moisture capacity | |
| 0-1 | 4.12 | 3.06 | 1.06 | 0.30 | 5.12 | 3.53 | 1.59 | 1.40 |
| 1-2 | 4.86 | 3.09 | 1.77 | 1.00 | 5.27 | 3.10 | 2.17 | 0.70 |
| 2-3 | 4.30 | 2.57 | 1.73 | 0.90 | 4.16 | 2.76 | 1.40 | 0.50 |
| 3-4 | 4.79 | 2.81 | 1.98 | 1.40 | 4.13 | 3.13 | 1.00 | 0.10 |
| 4-5 | 5.08 | 3.02 | 2.06 | 0.90 | 4.49 | 3.35 | 1.14 | 0.50 |
| | | | | | | | | |
| Depth in feet | 1960 | | | | | | | |
| | Experiment 3 | | | Field available moisture | Experiment 4 | | | Field available moisture |
| | Field capac- ity | Wilt- ing point | Available moisture capacity | | Field capac- ity | Wilt- ing point | Available moisture capacity | |
| 0-1 | 5.43 | 3.39 | 2.04 | 0.60 | 5.13 | 3.10 | 2.03 | 1.70 |
| 1-2 | 6.16 | 3.58 | 2.58 | 0.60 | 4.60 | 2.83 | 1.77 | 1.40 |
| 2-3 | 6.82 | 3.73 | 3.09 | 0.70 | 4.23 | 2.29 | 1.94 | 1.40 |
| 3-4 | 6.30 | 3.56 | 2.74 | 1.20 | 4.07 | 1.98 | 2.09 | 1.60 |
| 4-5 | 6.89 | 3.92 | 2.97 | 1.60 | 4.06 | 2.29 | 1.77 | 1.20 |
| | | | | | | | | |
| Depth in feet | 1961 | | | | | | | |
| | Experiment 5 | | | Field available moisture | Experiment 6 | | | Field available moisture |
| | Field capac- ity | Wilt- ing point | Available moisture capacity | | Field capac- ity | Wilt- ing point | Available moisture capacity | |
| 0-1 | 5.64 | 3.06 | 2.58 | 1.90 | 5.11 | 3.22 | 1.89 | 1.40 |
| 1-2 | 5.15 | 2.90 | 2.25 | 0.10 | 5.03 | 2.94 | 2.09 | 1.00 |
| 2-3 | 5.29 | 2.96 | 2.33 | 1.70 | 5.09 | 2.88 | 2.21 | 0.70 |
| 3-4 | 4.48 | 2.27 | 2.21 | 2.10 | 4.21 | 2.69 | 1.52 | 0.60 |
| 4-5 | 4.88 | 2.58 | 2.30 | 1.90 | 2.74 | 1.92 | 0.82 | 0.30 |

^aField capacity was determined in pressure apparatus at 1/3 atmosphere pressure. Wilting point was determined in pressure plate at 15 atmospheres pressure. Field available moisture was moisture present at sampling.

Table 52. (Continued)

| Depth in feet | Experiment 1 | | | | Experiment 2 | | | |
|---------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|
| | Field capac- ity | Wilt- ing point | Available moisture capacity | Field available moisture | Field capac- ity | Wilt- ing point | Available moisture capacity | Field available moisture |
| 0-1 | 4.52 | 2.91 | 1.61 | 0.90 | 4.53 | 2.68 | 1.85 | 1.30 |
| 1-2 | 4.74 | 2.87 | 1.87 | 0.60 | 4.83 | 2.80 | 2.03 | 1.40 |
| 2-3 | 4.86 | 2.61 | 2.25 | 1.20 | 4.90 | 2.60 | 2.30 | 1.50 |
| 3-4 | 4.76 | 2.16 | 2.60 | 2.40 | 5.39 | 2.56 | 2.83 | 2.30 |
| 4-5 | 5.02 | 2.20 | 2.82 | 2.80 | 4.87 | 2.08 | 2.79 | 2.80 |
| Experiment 3 | | | | Experiment 4 | | | | |
| 0-1 | 3.15 | 1.46 | 1.69 | 1.60 | 5.75 | 3.76 | 1.99 | 1.40 |
| 1-2 | 2.98 | 1.42 | 1.56 | 1.60 | 6.09 | 3.98 | 2.11 | 0.90 |
| 2-3 | 2.22 | 1.34 | 0.88 | 0.90 | 6.42 | 4.45 | 1.97 | 1.10 |
| 3-4 | 2.35 | 1.61 | 0.74 | 0.70 | 6.36 | 4.05 | 2.31 | 2.10 |
| 4-5 | 2.38 | 1.52 | 0.86 | 0.90 | 6.11 | 3.39 | 2.72 | 2.70 |
| Experiment 5 | | | | Experiment 6 | | | | |
| 0-1 | 3.61 | 2.06 | 1.55 | 1.40 | 3.55 | 1.75 | 1.80 | 1.40 |
| 1-2 | 3.80 | 1.89 | 1.91 | 1.90 | 3.73 | 1.76 | 1.97 | 2.00 |
| 2-3 | 3.69 | 1.71 | 1.98 | 2.00 | 3.59 | 1.70 | 1.89 | 1.90 |
| 3-4 | 3.68 | 1.39 | 2.29 | 2.30 | 3.46 | 1.54 | 1.92 | 1.90 |
| 4-5 | 3.68 | 1.36 | 2.32 | 2.30 | 4.08 | 1.88 | 2.20 | 2.20 |

Table 52. (Continued)

| Depth in feet | Experiment 7 | | | | Experiment 8 | | | |
|---------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|------------------------|-----------------------|-----------------------------------|--------------------------------|
| | Field capac- ity | Wilt- ing point | Available moisture capacity | Field available moisture | Field capac- ity | Wilt- ing point | Available moisture capacity | Field available moisture |
| 0-1 | 5.03 | 2.94 | 2.09 | 1.80 | 4.63 | 3.01 | 1.62 | 1.60 |
| 1-2 | 5.41 | 3.27 | 2.14 | 1.30 | 4.59 | 2.59 | 2.00 | 2.00 |
| 2-3 | 5.59 | 3.13 | 2.46 | 1.30 | 4.51 | 2.13 | 2.38 | 2.20 |
| 3-4 | 5.22 | 2.49 | 2.73 | 2.10 | 3.86 | 1.61 | 2.25 | 2.30 |
| 4-5 | 5.00 | 2.13 | 2.87 | 2.90 | 4.13 | 2.02 | 2.11 | 2.10 |
| Experiment 9 | | | | | Experiment 10 | | | |
| 0-1 | 5.62 | 3.60 | 2.02 | 1.90 | 3.82 | 1.61 | 2.22 | 2.20 |
| 1-2 | 6.12 | 4.03 | 2.09 | 0.90 | 4.35 | 1.66 | 2.69 | 2.50 |
| 2-3 | 6.71 | 4.58 | 2.13 | 0.50 | 3.63 | 1.46 | 2.17 | 2.20 |
| 3-4 | 6.79 | 4.69 | 2.10 | 1.00 | 2.86 | 1.00 | 1.86 | 1.90 |
| 4-5 | 6.41 | 3.38 | 3.03 | 2.00 | 3.07 | 1.31 | 1.76 | 1.80 |
| Experiment 11 | | | | | Experiment 12 | | | |
| 0-1 | 4.35 | 2.43 | 1.92 | 1.90 | 3.73 | 2.04 | 1.69 | 1.60 |
| 1-2 | 4.69 | 2.34 | 2.35 | 2.00 | 3.82 | 1.98 | 1.84 | 1.50 |
| 2-3 | 5.10 | 2.50 | 2.60 | 2.10 | 3.78 | 1.76 | 2.02 | 2.00 |
| 3-4 | 5.81 | 2.82 | 2.99 | 2.70 | 3.79 | 1.47 | 2.32 | 2.30 |
| 4-5 | 6.23 | 2.80 | 3.43 | 3.40 | 4.39 | 1.79 | 2.60 | 2.60 |

Table 53. 1959 stand levels, corn yields and N, P and K leaf contents of the individual treatments of the experiments by replicate

| Treatment number | Experiment 1 | | | | | | | | | |
|------------------|--------------------|--------------------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand ^a | Yield ^b | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.7 | 80.9 | 2.23 | 0.222 | 1.80 | 15.1 | 98.7 | 2.31 | 0.226 | 1.47 |
| 2 | 14.9 | 98.1 | 2.38 | 0.226 | 1.89 | 14.2 | 90.9 | 2.33 | 0.244 | 1.80 |
| 3 | 14.7 | 64.4 | 2.19 | 0.253 | 1.74 | 13.1 | 73.7 | 1.97 | 0.235 | 1.80 |
| 4 | 14.7 | 94.2 | 2.15 | 0.233 | 1.95 | 14.5 | 105.4 | 2.27 | 0.246 | 1.83 |
| 5 | 13.5 | 93.9 | 2.62 | 0.246 | 1.59 | 14.4 | 90.5 | 2.42 | 0.242 | 1.65 |
| 6 | 15.2 | 110.1 | 2.64 | 0.248 | 1.74 | 12.2 | 96.3 | 2.64 | 0.271 | 2.01 |
| 7 | 14.7 | 94.8 | 2.52 | 0.271 | 1.50 | 14.2 | 98.3 | 2.44 | 0.280 | 1.77 |
| 8 | 14.4 | 98.5 | 2.57 | 0.271 | 1.65 | 12.8 | 96.7 | 2.42 | 0.278 | 1.77 |
| 9 | 13.6 | 90.3 | 2.50 | 0.248 | 1.65 | 14.2 | 107.2 | 2.48 | 0.255 | 1.83 |
| 10 | 12.9 | 63.1 | 1.93 | 0.244 | 1.92 | 12.9 | 81.8 | 2.16 | 0.233 | 1.74 |
| 11 | 14.9 | 112.3 | 2.67 | 0.271 | 1.68 | 15.6 | 110.3 | 2.72 | 0.281 | 1.62 |
| 12 | 13.6 | 78.0 | 2.64 | 0.203 | 1.86 | 14.7 | 90.3 | 2.54 | 0.214 | 1.77 |
| 13 | 14.0 | 99.9 | 2.44 | 0.271 | 1.59 | 12.8 | 92.9 | 2.44 | 0.259 | 1.77 |
| 14 | 13.6 | 94.7 | 2.48 | 0.259 | 1.35 | 14.5 | 99.3 | 2.35 | 0.235 | 1.44 |
| 15 | 14.5 | 110.3 | 2.40 | 0.253 | 1.95 | 14.2 | 111.1 | 2.59 | 0.256 | 1.80 |
| 16 | 14.4 | 66.9 | 1.80 | 0.229 | 1.95 | 12.9 | 78.8 | 1.89 | 0.233 | 1.95 |
| 17 | 14.7 | 87.7 | 2.75 | 0.231 | 1.98 | 13.3 | 78.9 | 2.86 | 0.218 | 2.04 |
| 18 | 14.5 | 102.8 | 2.70 | 0.276 | 1.17 | 15.4 | 110.4 | 2.65 | 0.277 | 1.11 |
| 19 | 13.6 | 74.9 | 2.06 | 0.197 | 1.65 | 13.1 | 73.4 | 2.11 | 0.200 | 1.77 |

^aStand is thousands of stalks per acre.

^bYield is bushels per acre at a common 15.5 percent moisture level.

Table 53. (Continued)

| Treatment number | Experiment 2 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 15.8 | 96.0 | 2.31 | 0.246 | 0.72 | 13.5 | 100.5 | 2.42 | 0.253 | 0.66 |
| 2 | 14.8 | 102.0 | 2.34 | 0.255 | 1.23 | 15.4 | 102.3 | 2.21 | 0.238 | 0.81 |
| 3 | 15.8 | 113.7 | 2.31 | 0.286 | 0.84 | 15.8 | 100.0 | 2.38 | 0.269 | 1.05 |
| 4 | 16.4 | 116.6 | 2.26 | 0.258 | 0.84 | 14.6 | 117.4 | 2.42 | 0.285 | 0.51 |
| 5 | 16.6 | 109.7 | 2.62 | 0.283 | 1.11 | 16.4 | 86.1 | 2.51 | 0.287 | 0.42 |
| 6 | 17.3 | 119.1 | 2.55 | 0.288 | 1.35 | 13.9 | 101.9 | 2.36 | 0.283 | 0.36 |
| 7 | 17.1 | 105.8 | 2.49 | 0.290 | 0.60 | 16.6 | 93.6 | 2.51 | 0.332 | 0.45 |
| 8 | 16.0 | 105.6 | 2.49 | 0.283 | 1.02 | 17.1 | 104.9 | 2.51 | 0.273 | 1.02 |
| 9 | 17.1 | 114.6 | 2.55 | 0.271 | 0.69 | 15.0 | 89.2 | 2.47 | 0.273 | 0.54 |
| 10 | 13.3 | 100.7 | 2.44 | 0.246 | 0.87 | 13.7 | 78.0 | 2.10 | 0.251 | 0.48 |
| 11 | 14.8 | 92.7 | 2.57 | 0.255 | 0.78 | 15.8 | 95.2 | 2.67 | 0.260 | 0.72 |
| 12 | 16.4 | 106.0 | 2.51 | 0.257 | 1.14 | 14.8 | 71.6 | 2.19 | 0.217 | 0.48 |
| 13 | 15.6 | 116.5 | 2.42 | 0.271 | 0.78 | 15.4 | 108.9 | 2.57 | 0.297 | 0.48 |
| 14 | 14.6 | 91.2 | 2.42 | 0.302 | 0.54 | 13.3 | 84.4 | 2.47 | 0.264 | 0.57 |
| 15 | 15.4 | 108.7 | 2.67 | 0.283 | 1.65 | 13.5 | 114.0 | 2.42 | 0.249 | 0.51 |
| 16 | 15.6 | 117.2 | 2.40 | 0.264 | 1.29 | 16.2 | 117.4 | 2.29 | 0.262 | 1.11 |
| 17 | 16.4 | 113.2 | 2.67 | 0.285 | 1.53 | 17.1 | 111.8 | 2.55 | 0.225 | 1.05 |
| 18 | 14.6 | 95.5 | 2.62 | 0.321 | 0.54 | 16.6 | 107.3 | 2.62 | 0.319 | 1.20 |
| 19 | 14.4 | 86.2 | 2.29 | 0.231 | 0.63 | 15.0 | 80.1 | 2.33 | 0.271 | 0.99 |

Table 53. (Continued)

| Treatment number | Experiment 3 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 13.6 | 93.2 | 2.36 | 0.253 | 1.44 | 9.6 | 72.4 | 2.36 | 0.240 | 1.47 |
| 2 | 13.8 | 89.4 | 2.27 | 0.233 | 1.62 | 12.9 | 74.4 | 1.81 | 0.218 | 1.89 |
| 3 | 12.3 | 80.8 | 2.65 | 0.309 | 0.96 | 14.2 | 96.4 | 2.10 | 0.262 | 1.29 |
| 4 | 15.1 | 106.8 | 2.24 | 0.244 | 1.62 | 13.8 | 68.9 | 1.76 | 0.244 | 1.74 |
| 5 | 15.1 | 105.0 | 2.62 | 0.255 | 1.32 | 14.9 | 104.4 | 2.52 | 0.251 | 1.56 |
| 6 | 14.5 | 110.2 | 2.70 | 0.271 | 1.29 | 16.2 | 110.0 | 2.48 | 0.253 | 1.62 |
| 7 | 15.8 | 119.3 | 2.50 | 0.273 | 1.23 | 13.8 | 110.9 | 2.52 | 0.287 | 1.20 |
| 8 | 15.8 | 112.6 | 2.43 | 0.280 | 1.05 | 14.2 | 105.9 | 2.55 | 0.271 | 1.41 |
| 9 | 14.7 | 117.2 | 2.55 | 0.276 | 1.26 | 13.8 | 106.9 | 2.31 | 0.248 | 1.41 |
| 10 | 14.9 | 85.2 | 1.89 | 0.244 | 1.53 | 14.5 | 69.6 | 1.66 | 0.206 | 1.83 |
| 11 | 14.5 | 103.0 | 2.55 | 0.276 | 1.20 | 16.6 | 96.7 | 2.67 | 0.266 | 1.50 |
| 12 | 14.4 | 98.6 | 2.57 | 0.251 | 1.17 | 14.7 | 107.2 | 2.52 | 0.248 | 1.35 |
| 13 | 13.3 | 96.7 | 2.48 | 0.292 | 1.20 | 15.1 | 90.6 | 2.17 | 0.244 | 1.56 |
| 14 | 15.5 | 96.8 | 2.43 | 0.259 | 1.17 | 14.4 | 103.6 | 2.36 | 0.242 | 1.32 |
| 15 | 14.0 | 104.8 | 2.60 | 0.269 | 1.59 | 14.8 | 105.9 | 2.31 | 0.235 | 1.89 |
| 16 | 13.8 | 73.5 | 1.72 | 0.271 | 1.86 | 14.7 | 66.9 | 1.78 | 0.244 | 1.95 |
| 17 | 14.8 | 102.7 | 2.68 | 0.235 | 1.65 | 12.9 | 80.5 | 2.64 | 0.201 | 1.59 |
| 18 | 15.8 | 102.2 | 2.75 | 0.335 | 0.84 | 15.5 | 103.8 | 2.52 | 0.273 | 0.90 |
| 19 | 11.4 | 79.0 | 2.36 | 0.242 | 1.14 | 14.0 | 74.4 | 1.97 | 0.206 | 1.62 |

Table 53. (Continued)

| Treatment number | Experiment 4 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 12.2 | 85.7 | 2.99 | 0.308 | 0.96 | 11.6 | 77.2 | 2.99 | 0.317 | 0.96 |
| 2 | 12.0 | 91.6 | 2.89 | 0.308 | 1.23 | 13.3 | 93.8 | 2.86 | 0.298 | 1.11 |
| 3 | 13.6 | 88.7 | 2.81 | 0.308 | 0.96 | 11.8 | 74.1 | 2.91 | 0.303 | 0.99 |
| 4 | 12.4 | 77.6 | 2.76 | 0.293 | 1.14 | 13.1 | 90.4 | 2.93 | 0.303 | 1.20 |
| 5 | 13.6 | 103.0 | 2.97 | 0.303 | 0.93 | 12.2 | 77.0 | 3.18 | 0.305 | 1.02 |
| 6 | 13.1 | 101.0 | 2.97 | 0.298 | 1.23 | 10.9 | 80.4 | 3.07 | 0.303 | 1.32 |
| 7 | 13.5 | 82.8 | 3.13 | 0.337 | 0.93 | 13.6 | 95.0 | 3.07 | 0.317 | 1.08 |
| 8 | 13.3 | 96.3 | 2.99 | 0.303 | 1.08 | 14.0 | 85.1 | 3.04 | 0.317 | 1.11 |
| 9 | 12.5 | 83.6 | 2.99 | 0.305 | 1.02 | 12.0 | 84.6 | 3.04 | 0.291 | 1.08 |
| 10 | 12.9 | 84.7 | 2.92 | 0.310 | 1.08 | 12.4 | 77.5 | 2.62 | 0.284 | 1.17 |
| 11 | 13.8 | 84.1 | 2.86 | 0.303 | 1.14 | 11.3 | 78.2 | 3.11 | 0.303 | 1.23 |
| 12 | 13.1 | 85.0 | 2.94 | 0.298 | 1.02 | 12.2 | 86.6 | 3.13 | 0.286 | 1.35 |
| 13 | 12.9 | 86.4 | 2.92 | 0.322 | 1.08 | 12.5 | 86.7 | 2.96 | 0.298 | 1.17 |
| 14 | 13.1 | 73.0 | 2.72 | 0.367 | 0.75 | 11.5 | 68.1 | 2.80 | 0.293 | 0.81 |
| 15 | 13.3 | 94.3 | 2.97 | 0.298 | 1.26 | 13.5 | 87.2 | 2.91 | 0.308 | 1.26 |
| 16 | 12.9 | 90.7 | 2.92 | 0.312 | 1.23 | 13.5 | 83.8 | 2.93 | 0.281 | 1.47 |
| 17 | 12.9 | 92.3 | 3.17 | 0.300 | 1.32 | 11.3 | 86.6 | 2.96 | 0.291 | 1.56 |
| 18 | 13.6 | 80.0 | 3.19 | 0.327 | 0.81 | 12.0 | 76.1 | 2.99 | 0.325 | 0.90 |
| 19 | 10.9 | 65.6 | 2.78 | 0.327 | 0.75 | 11.3 | 73.2 | 3.04 | 0.293 | 1.05 |

Table 53. (Continued)

| Treatment number | Experiment 5 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 15.9 | 108.6 | 2.23 | 0.296 | 1.29 | 16.1 | 108.1 | 2.68 | 0.329 | 1.59 |
| 2 | 15.9 | 106.5 | 2.47 | 0.289 | 1.71 | 15.7 | 96.2 | 2.47 | 0.306 | 1.65 |
| 3 | 15.3 | 105.0 | 2.86 | 0.358 | 1.17 | 15.1 | 98.8 | 2.54 | 0.296 | 1.02 |
| 4 | 16.3 | 106.3 | 2.32 | 0.353 | 1.47 | 16.1 | 101.3 | 2.78 | 0.353 | 1.47 |
| 5 | 16.3 | 117.6 | 2.68 | 0.332 | 1.59 | 15.7 | 112.4 | 2.78 | 0.314 | 1.17 |
| 6 | 15.5 | 109.1 | 2.84 | 0.306 | 1.32 | 15.5 | 112.6 | 2.75 | 0.337 | 1.65 |
| 7 | 16.7 | 123.2 | 2.78 | 0.332 | 1.20 | 15.9 | 118.8 | 2.84 | 0.308 | 1.29 |
| 8 | 17.1 | 118.2 | 2.70 | 0.347 | 1.23 | 14.9 | 114.9 | 2.60 | 0.316 | 1.50 |
| 9 | 16.3 | 114.9 | 2.73 | 0.347 | 1.20 | 15.3 | 105.7 | 2.58 | 0.317 | 1.50 |
| 10 | 16.3 | 100.3 | 2.31 | 0.314 | 1.89 | 15.5 | 76.9 | 2.13 | 0.310 | 1.65 |
| 11 | 16.5 | 106.1 | 2.84 | 0.326 | 1.11 | 15.7 | 107.0 | 2.93 | 0.346 | 1.32 |
| 12 | 15.5 | 104.6 | 2.84 | 0.272 | 1.23 | 15.5 | 110.0 | 2.72 | 0.338 | 1.65 |
| 13 | 16.1 | 116.9 | 2.68 | 0.358 | 1.95 | 15.9 | 114.8 | 2.77 | 0.341 | 1.50 |
| 14 | 16.1 | 106.8 | 2.84 | 0.332 | 1.11 | 15.3 | 105.4 | 2.79 | 0.320 | 0.99 |
| 15 | 15.1 | 113.0 | 2.65 | 0.332 | 1.41 | 16.7 | 109.2 | 2.59 | 0.325 | 1.74 |
| 16 | 14.9 | 95.3 | 2.31 | 0.314 | 1.92 | 15.9 | 94.0 | 2.25 | 0.295 | 1.71 |
| 17 | 15.9 | 112.5 | 2.73 | 0.304 | 1.47 | 15.3 | 106.4 | 2.93 | 0.313 | 1.26 |
| 18 | 16.3 | 125.3 | 2.73 | 0.347 | 1.50 | 15.3 | 104.1 | 2.83 | 0.341 | 0.90 |
| 19 | 15.7 | 98.7 | 2.75 | 0.282 | 1.23 | 14.9 | 85.4 | 2.15 | 0.288 | 1.62 |

Table 53. (Continued)

| Treatment number | Experiment 6 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.3 | 111.5 | 2.90 | 0.313 | 1.62 | 14.5 | 105.9 | 2.83 | 0.313 | 1.26 |
| 2 | 14.1 | 99.9 | 2.51 | 0.283 | 1.89 | 14.1 | 104.4 | 2.72 | 0.302 | 1.62 |
| 3 | 14.3 | 94.8 | 2.56 | 0.293 | 1.77 | 14.6 | 109.0 | 2.67 | 0.309 | 1.41 |
| 4 | 13.2 | 106.2 | 2.67 | 0.310 | 1.74 | 14.3 | 102.0 | 2.93 | 0.316 | 1.65 |
| 5 | 13.5 | 107.0 | 2.83 | 0.298 | 1.41 | 13.9 | 109.1 | 3.12 | 0.307 | 1.26 |
| 6 | 14.3 | 114.7 | 2.88 | 0.300 | 1.77 | 14.3 | 111.0 | 2.88 | 0.302 | 1.68 |
| 7 | 14.8 | 111.0 | 2.99 | 0.333 | 1.56 | 14.1 | 107.9 | 2.98 | 0.319 | 1.20 |
| 8 | 15.2 | 119.7 | 2.67 | 0.307 | 1.74 | 15.6 | 103.9 | 2.80 | 0.340 | 1.86 |
| 9 | 13.9 | 110.5 | 2.83 | 0.320 | 1.62 | 14.1 | 100.7 | 2.88 | 0.307 | 1.41 |
| 10 | 13.3 | 100.6 | 2.51 | 0.308 | 1.80 | 13.5 | 88.9 | 2.44 | 0.283 | 1.50 |
| 11 | 14.5 | 102.8 | 2.99 | 0.333 | 1.47 | 14.5 | 109.3 | 3.06 | 0.337 | 1.62 |
| 12 | 14.1 | 115.0 | 2.83 | 0.310 | 1.71 | 14.5 | 108.8 | 2.98 | 0.304 | 1.41 |
| 13 | 14.3 | 103.3 | 2.69 | 0.303 | 1.56 | 13.9 | 112.7 | 2.72 | 0.302 | 1.26 |
| 14 | 14.1 | 110.5 | 2.88 | 0.318 | 1.44 | 13.9 | 99.4 | 2.77 | 0.307 | 0.87 |
| 15 | 13.7 | 104.3 | 2.88 | 0.336 | 1.77 | 14.8 | 102.5 | 2.69 | 0.302 | 1.62 |
| 16 | 13.5 | 89.7 | 2.41 | 0.313 | 1.84 | 13.9 | 93.7 | 2.47 | 0.302 | 1.68 |
| 17 | 14.1 | 111.6 | 2.88 | 0.313 | 1.59 | 14.6 | 105.3 | 2.74 | 0.294 | 1.74 |
| 18 | 13.9 | 112.0 | 2.99 | 0.352 | 1.56 | 14.1 | 104.5 | 2.98 | 0.329 | 1.11 |
| 19 | 13.5 | 99.5 | 2.59 | 0.303 | 1.56 | 13.2 | 95.2 | 2.74 | 0.297 | 1.26 |

Table 54. 1960 stand levels, corn yields and N, P and K leaf contents of the individual treatments of the experiments by replicate

| Treatment number | Experiment 1 | | | | | | | | | |
|------------------|--------------------|--------------------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand ^a | Yield ^b | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.4 | 88.5 | 2.24 | 0.277 | 2.01 | 14.2 | 86.7 | 2.40 | 0.261 | 1.83 |
| 2 | 14.2 | 106.4 | 2.62 | 0.270 | 1.98 | 13.4 | 93.4 | 2.45 | 0.298 | 2.13 |
| 3 | 12.8 | 90.6 | 2.60 | 0.279 | 1.65 | 13.0 | 89.4 | 2.63 | 0.271 | 1.68 |
| 4 | 12.0 | 97.2 | 2.27 | 0.308 | 1.86 | 14.2 | 106.6 | 2.36 | 0.303 | 1.83 |
| 5 | 14.8 | 107.6 | 2.70 | 0.276 | 1.44 | 13.6 | 84.5 | 2.69 | 0.276 | 1.50 |
| 6 | 12.6 | 56.1 | 2.50 | 0.296 | 1.68 | 13.2 | 87.4 | 2.58 | 0.294 | 1.74 |
| 7 | 15.6 | 110.7 | 2.57 | 0.291 | 1.50 | 14.4 | 112.3 | 2.67 | 0.298 | 1.17 |
| 8 | 13.0 | 63.4 | 2.65 | 0.325 | 1.83 | 14.8 | 94.3 | 2.83 | 0.314 | 1.68 |
| 9 | 13.8 | 76.6 | 2.32 | 0.290 | 1.68 | 13.4 | 77.6 | 2.54 | 0.297 | 1.74 |
| 10 | 13.4 | 78.5 | 2.14 | 0.276 | 1.95 | 13.6 | 82.9 | 1.99 | 0.257 | 1.65 |
| 11 | 15.2 | 99.1 | 2.69 | 0.296 | 1.56 | 13.8 | 92.3 | 2.69 | 0.306 | 1.86 |
| 12 | 15.4 | 80.0 | 2.78 | 0.286 | 1.77 | 12.2 | 77.9 | 2.67 | 0.289 | 1.62 |
| 13 | 13.4 | 98.0 | 2.45 | 0.338 | 1.56 | 13.0 | 85.8 | 2.69 | 0.368 | 1.59 |
| 14 | 13.8 | 96.0 | 2.43 | 0.328 | 1.56 | 15.2 | 106.3 | 2.67 | 0.275 | 2.25 |
| 15 | 15.2 | 97.3 | 2.33 | 0.261 | 1.74 | 14.8 | 102.9 | 2.49 | 0.279 | 1.89 |
| 16 | 13.4 | 74.6 | 2.33 | 0.257 | 1.89 | 13.8 | 78.2 | 2.38 | 0.246 | 2.19 |
| 17 | 13.0 | 77.2 | 2.49 | 0.275 | 1.62 | 15.0 | 72.9 | 2.36 | 0.275 | 1.71 |
| 18 | 14.4 | 61.6 | 2.27 | 0.257 | 1.98 | 14.8 | 90.6 | 2.49 | 0.294 | 2.13 |
| 19 | 13.2 | 87.4 | 2.64 | 0.291 | 1.68 | 13.4 | 97.9 | 2.84 | 0.268 | 1.59 |
| 20 | 14.2 | 83.1 | 2.54 | 0.286 | 2.01 | 13.4 | 93.0 | 2.67 | 0.286 | 1.98 |
| 21 | 13.4 | 102.0 | 2.49 | 0.352 | 1.20 | 14.0 | 86.9 | 2.81 | 0.295 | 1.65 |
| 22 | 14.4 | 60.5 | 2.62 | 0.315 | 1.80 | 15.0 | 102.9 | 2.58 | 0.300 | 1.98 |
| 23 | 14.4 | 79.7 | 2.40 | 0.246 | 1.62 | 11.9 | 86.4 | 2.41 | 0.272 | 1.65 |

^aStand is thousands of stalks per acre.

^bYield is bushels per acre at a common 15.5 percent moisture level.

Table 54. (Continued)

| Treatment number | Experiment 2 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 18.4 | 76.9 | 2.03 | 0.214 | 1.65 | 15.8 | 90.2 | 2.33 | 0.246 | 1.77 |
| 2 | 16.3 | 90.2 | 2.40 | 0.249 | 1.86 | 15.8 | 83.2 | 2.49 | 0.257 | 1.62 |
| 3 | 15.2 | 82.4 | 2.38 | 0.262 | 1.47 | 18.6 | 95.5 | 2.45 | 0.255 | 1.77 |
| 4 | 17.8 | 136.3 | 2.33 | 0.264 | 1.50 | 17.3 | 84.4 | 2.19 | 0.229 | 1.77 |
| 5 | 16.1 | 77.8 | 2.55 | 0.267 | 1.41 | 18.2 | 94.6 | 2.45 | 0.249 | 1.65 |
| 6 | 15.4 | 79.9 | 2.49 | 0.257 | 1.83 | 17.5 | 99.9 | 2.55 | 0.264 | 1.80 |
| 7 | 15.6 | 85.0 | 2.47 | 0.285 | 1.23 | 16.5 | 98.6 | 2.58 | 0.264 | 1.74 |
| 8 | 18.2 | 94.3 | 2.49 | 0.269 | 1.65 | 15.6 | 89.2 | 2.40 | 0.269 | 1.68 |
| 9 | 17.1 | 84.9 | 2.30 | 0.255 | 1.20 | 17.5 | 91.7 | 2.38 | 0.249 | 1.77 |
| 10 | 18.6 | 88.1 | 2.21 | 0.242 | 1.50 | 16.5 | 81.7 | 2.13 | 0.231 | 1.98 |
| 11 | 18.2 | 97.4 | 2.65 | 0.276 | 1.56 | 18.0 | 90.7 | 2.61 | 0.264 | 1.89 |
| 12 | 17.8 | 98.4 | 2.58 | 0.238 | 1.71 | 17.1 | 79.7 | 2.45 | 0.220 | 1.77 |
| 13 | 17.3 | 84.2 | 2.49 | 0.269 | 1.62 | 17.5 | 79.8 | 2.48 | 0.255 | 2.07 |
| 14 | 17.3 | 98.2 | 2.53 | 0.255 | 1.32 | 17.3 | 99.3 | 2.50 | 0.246 | 1.65 |
| 15 | 17.5 | 83.9 | 2.45 | 0.246 | 1.65 | 17.1 | 99.0 | 2.45 | 0.251 | 1.92 |
| 16 | 16.5 | 88.1 | 2.36 | 0.238 | 1.98 | 15.2 | 74.5 | 2.22 | 0.220 | 1.77 |
| 17 | 18.6 | 80.3 | 1.89 | 0.218 | 1.59 | 15.6 | 89.5 | 2.17 | 0.229 | 1.65 |
| 18 | 16.7 | 88.5 | 2.05 | 0.235 | 1.86 | 14.8 | 94.6 | 2.31 | 0.246 | 2.10 |
| 19 | 17.8 | 85.9 | 2.60 | 0.238 | 1.74 | 17.5 | 96.7 | 2.61 | 0.231 | 1.86 |
| 20 | 17.5 | 79.1 | 2.40 | 0.214 | 1.86 | 17.8 | 81.3 | 2.50 | 0.238 | 2.04 |
| 21 | 18.2 | 95.8 | 2.45 | 0.310 | 1.05 | 15.8 | 101.0 | 2.63 | 0.288 | 1.44 |
| 22 | 17.1 | 91.1 | 2.49 | 0.297 | 1.89 | 17.1 | 97.2 | 2.53 | 0.297 | 2.07 |
| 23 | 17.1 | 57.7 | 1.66 | 0.192 | 1.86 | 14.4 | 65.8 | 2.13 | 0.218 | 1.68 |

Table 54. (Continued)

| Treatment number | Experiment 3 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 13.4 | 106.8 | 2.76 | 0.315 | 1.95 | 17.2 | 107.1 | 2.52 | 0.305 | 1.41 |
| 2 | 15.5 | 104.6 | 2.46 | 0.300 | 1.77 | 16.3 | 114.9 | 2.76 | 0.315 | 1.77 |
| 3 | 13.2 | 94.4 | 2.59 | 0.290 | 2.22 | 14.9 | 105.8 | 2.65 | 0.310 | 1.35 |
| 4 | 15.9 | 107.2 | 2.76 | 0.335 | 1.59 | 14.9 | 101.5 | 2.56 | 0.305 | 1.89 |
| 5 | 14.5 | 87.7 | 2.86 | 0.325 | 1.26 | 14.9 | 96.5 | 2.85 | 0.297 | 1.41 |
| 6 | 13.6 | 108.8 | 2.67 | 0.327 | 1.50 | 15.1 | 113.5 | 2.74 | 0.315 | 1.47 |
| 7 | 15.9 | 95.4 | 2.76 | 0.335 | 1.32 | 16.1 | 103.6 | 2.68 | 0.335 | 1.32 |
| 8 | 14.9 | 105.4 | 2.83 | 0.359 | 1.56 | 15.7 | 117.8 | 2.74 | 0.317 | 1.41 |
| 9 | 14.9 | 97.9 | 2.86 | 0.322 | 1.50 | 15.1 | 119.2 | 2.74 | 0.295 | 1.44 |
| 10 | 10.7 | 68.9 | 2.05 | 0.293 | 1.62 | 15.3 | 64.5 | 1.73 | 0.266 | 1.95 |
| 11 | 16.9 | 100.3 | 2.89 | 0.332 | 1.14 | 14.1 | 94.9 | 2.95 | 0.322 | 1.53 |
| 12 | 15.5 | 119.1 | 2.89 | 0.351 | 1.38 | 12.8 | 85.5 | 2.72 | 0.295 | 1.62 |
| 13 | 13.4 | 96.1 | 2.65 | 0.330 | 1.80 | 16.5 | 111.0 | 2.56 | 0.325 | 1.23 |
| 14 | 13.2 | 94.0 | 2.63 | 0.356 | 1.02 | 16.1 | 95.0 | 2.69 | 0.343 | 0.90 |
| 15 | 13.8 | 99.7 | 2.70 | 0.325 | 1.62 | 15.3 | 104.7 | 2.74 | 0.302 | 1.62 |
| 16 | 14.9 | 80.1 | 2.28 | 0.285 | 1.71 | 14.1 | 72.2 | 2.07 | 0.259 | 1.68 |
| 17 | 15.3 | 80.3 | 1.96 | 0.264 | 1.98 | 15.1 | 76.9 | 1.94 | 0.279 | 1.77 |
| 18 | 14.1 | 75.6 | 2.10 | 0.290 | 1.77 | 14.5 | 63.0 | 2.00 | 0.261 | 1.95 |
| 19 | 15.3 | 94.7 | 2.91 | 0.343 | 0.99 | 14.5 | 100.1 | 2.83 | 0.331 | 1.08 |
| 20 | 17.4 | 112.1 | 2.79 | 0.288 | 1.47 | 16.1 | 113.1 | 2.67 | 0.298 | 1.41 |
| 21 | 14.9 | 95.5 | 2.78 | 0.389 | 0.84 | 11.2 | 88.0 | 3.07 | 0.353 | 0.96 |
| 22 | 12.4 | 90.6 | 2.83 | 0.348 | 1.50 | 14.9 | 110.1 | 2.83 | 0.310 | 1.71 |
| 23 | 14.5 | 76.0 | 2.18 | 0.258 | 1.44 | 15.1 | 93.1 | 2.49 | 0.312 | 1.56 |

Table 54. (Continued)

| Treatment number | Experiment 4 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.4 | 75.5 | 2.04 | 0.214 | 1.92 | 12.4 | 80.9 | 2.26 | 0.227 | 1.95 |
| 2 | 13.6 | 81.4 | 2.17 | 0.225 | 2.16 | 15.1 | 99.9 | 2.35 | 0.225 | 2.49 |
| 3 | 13.4 | 86.2 | 2.33 | 0.245 | 1.74 | 14.4 | 104.2 | 2.50 | 0.231 | 2.31 |
| 4 | 13.8 | 82.5 | 2.10 | 0.236 | 2.07 | 14.0 | 97.9 | 2.33 | 0.236 | 2.34 |
| 5 | 12.2 | 101.3 | 2.80 | 0.262 | 1.95 | 14.6 | 105.3 | 2.75 | 0.242 | 1.62 |
| 6 | 12.6 | 102.1 | 2.72 | 0.245 | 1.74 | 13.6 | 107.9 | 2.59 | 0.253 | 1.95 |
| 7 | 13.4 | 114.7 | 2.70 | 0.288 | 1.65 | 13.4 | 94.2 | 2.62 | 0.253 | 1.53 |
| 8 | 13.6 | 106.7 | 2.65 | 0.291 | 1.74 | 14.8 | 104.9 | 2.75 | 0.262 | 1.62 |
| 9 | 13.8 | 102.8 | 2.59 | 0.262 | 1.98 | 14.0 | 103.1 | 2.54 | 0.242 | 1.59 |
| 10 | 13.0 | 66.1 | 1.89 | 0.221 | 1.74 | 14.6 | 93.0 | 2.14 | 0.236 | 2.25 |
| 11 | 12.4 | 96.6 | 2.65 | 0.265 | 1.50 | 13.0 | 108.8 | 2.63 | 0.260 | 1.38 |
| 12 | 13.2 | 84.9 | 2.57 | 0.221 | 2.16 | 13.2 | 83.7 | 2.63 | 0.214 | 1.83 |
| 13 | 13.2 | 97.0 | 2.50 | 0.267 | 1.74 | 14.8 | 103.1 | 2.41 | 0.253 | 1.62 |
| 14 | 14.6 | 100.8 | 2.57 | 0.258 | 1.59 | 12.8 | 96.0 | 2.56 | 0.272 | 1.47 |
| 15 | 15.7 | 109.6 | 2.43 | 0.249 | 1.86 | 14.4 | 114.6 | 2.51 | 0.253 | 2.19 |
| 16 | 13.6 | 55.7 | 1.64 | 0.198 | 2.13 | 14.0 | 74.3 | 2.12 | 0.210 | 1.95 |
| 17 | 14.6 | 53.0 | 1.70 | 0.262 | 1.89 | 13.8 | 74.6 | 2.00 | 0.240 | 2.34 |
| 18 | 12.6 | 78.2 | 1.89 | 0.265 | 1.92 | 13.8 | 86.1 | 2.04 | 0.236 | 2.55 |
| 19 | 14.0 | 73.3 | 2.77 | 0.185 | 1.68 | 14.0 | 89.0 | 2.77 | 0.196 | 1.56 |
| 20 | 14.2 | 100.8 | 2.59 | 0.218 | 1.89 | 14.2 | 85.4 | 2.72 | 0.210 | 1.68 |
| 21 | 14.2 | 111.5 | 2.72 | 0.286 | 1.74 | 12.8 | 115.5 | 2.77 | 0.293 | 1.53 |
| 22 | 13.0 | 109.6 | 2.65 | 0.305 | 1.92 | 14.2 | 116.0 | 2.82 | 0.291 | 1.68 |
| 23 | 13.6 | 71.4 | 2.19 | 0.210 | 1.74 | 12.8 | 69.8 | 2.35 | 0.196 | 1.77 |

Table 54. (Continued)

| Treatment number | Experiment 5 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 13.2 | 86.3 | 2.22 | 0.231 | 1.29 | 12.8 | 89.7 | 2.37 | 0.238 | 1.35 |
| 2 | 10.2 | 59.5 | 2.20 | 0.275 | 1.65 | 13.6 | 99.8 | 2.34 | 0.255 | 1.65 |
| 3 | 13.0 | 85.1 | 2.13 | 0.240 | 1.74 | 13.8 | 103.0 | 2.22 | 0.263 | 1.20 |
| 4 | 12.4 | 91.1 | 2.32 | 0.263 | 1.65 | 14.1 | 108.2 | 2.29 | 0.261 | 1.41 |
| 5 | 13.2 | 100.0 | 2.56 | 0.255 | 1.23 | 13.2 | 116.5 | 2.80 | 0.275 | 1.11 |
| 6 | 14.1 | 102.6 | 2.80 | 0.263 | 1.50 | 13.8 | 105.5 | 2.66 | 0.277 | 1.35 |
| 7 | 13.4 | 107.7 | 2.39 | 0.257 | 1.11 | 14.5 | 114.6 | 2.59 | 0.271 | 0.93 |
| 8 | 13.4 | 92.2 | 2.08 | 0.270 | 1.68 | 13.9 | 109.5 | 2.53 | 0.284 | 1.29 |
| 9 | 13.2 | 89.9 | 2.16 | 0.246 | 1.50 | 14.5 | 117.6 | 2.51 | 0.259 | 1.29 |
| 10 | 14.3 | 64.6 | 1.65 | 0.199 | 1.68 | 12.6 | 56.8 | 1.57 | 0.217 | 1.35 |
| 11 | 14.9 | 132.7 | 2.64 | 0.281 | 1.62 | 13.2 | 101.6 | 2.56 | 0.275 | 0.84 |
| 12 | 14.5 | 77.0 | 2.22 | 0.191 | 1.35 | 13.6 | 103.4 | 2.64 | 0.244 | 1.29 |
| 13 | 13.8 | 104.1 | 2.53 | 0.288 | 2.01 | 14.9 | 117.2 | 2.43 | 0.275 | 1.14 |
| 14 | 13.8 | 99.1 | 2.46 | 0.259 | 1.77 | 13.4 | 105.5 | 2.64 | 0.281 | 0.90 |
| 15 | 12.6 | 99.7 | 2.72 | 0.285 | 1.80 | 13.8 | 109.6 | 2.72 | 0.274 | 1.44 |
| 16 | 13.6 | 68.2 | 1.93 | 0.219 | 1.86 | 13.2 | 58.1 | 1.75 | 0.186 | 1.35 |
| 17 | 12.4 | 58.5 | 1.84 | 0.242 | 1.95 | 13.2 | 83.6 | 1.91 | 0.242 | 1.23 |
| 18 | 13.0 | 55.3 | 1.86 | 0.270 | 1.80 | 12.8 | 80.9 | 1.84 | 0.283 | 1.59 |
| 19 | 13.2 | 104.1 | 3.01 | 0.268 | 1.62 | 12.6 | 96.3 | 2.67 | 0.265 | 0.96 |
| 20 | 14.5 | 105.9 | 2.96 | 0.268 | 1.92 | 13.2 | 101.1 | 2.78 | 0.256 | 1.59 |
| 21 | 13.9 | 90.8 | 2.51 | 0.261 | 1.29 | 14.9 | 115.4 | 2.76 | 0.290 | 1.11 |
| 22 | 12.6 | 103.4 | 2.75 | 0.300 | 1.71 | 15.8 | 116.0 | 2.59 | 0.307 | 1.14 |
| 23 | 14.1 | 67.2 | 1.92 | 0.188 | 1.71 | 13.4 | 78.5 | 2.10 | 0.233 | 1.26 |

Table 54. (Continued)

| Treatment number | Experiment 6 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 11.2 | 69.9 | 2.72 | 0.279 | 1.95 | 12.9 | 72.9 | 2.67 | 0.276 | 2.07 |
| 2 | 13.3 | 69.7 | 2.32 | 0.245 | 1.95 | 13.8 | 89.1 | 2.70 | 0.290 | 2.01 |
| 3 | 13.8 | 91.9 | 2.40 | 0.273 | 2.37 | 13.4 | 75.4 | 2.99 | 0.309 | 2.01 |
| 4 | 12.5 | 73.5 | 2.62 | 0.279 | 2.07 | 12.3 | 79.9 | 2.22 | 0.260 | 2.16 |
| 5 | 12.9 | 97.5 | 2.86 | 0.258 | 1.74 | 13.1 | 119.2 | 2.93 | 0.295 | 2.04 |
| 6 | 10.7 | 76.8 | 2.91 | 0.260 | 1.98 | 11.8 | 86.5 | 2.55 | 0.302 | 2.28 |
| 7 | 12.3 | 96.6 | 2.60 | 0.260 | 1.80 | 13.1 | 114.3 | 2.93 | 0.307 | 1.95 |
| 8 | 13.1 | 96.3 | 2.70 | 0.276 | 1.80 | 13.3 | 86.3 | 2.81 | 0.298 | 2.16 |
| 9 | 12.3 | 100.3 | 2.76 | 0.298 | 2.22 | 12.5 | 105.8 | 2.78 | 0.298 | 2.16 |
| 10 | 11.6 | 61.2 | 2.53 | 0.256 | 1.86 | 12.5 | 66.1 | 2.91 | 0.327 | 1.92 |
| 11 | 12.9 | 109.6 | 3.11 | 0.293 | 2.10 | 13.3 | 129.2 | 2.99 | 0.312 | 2.19 |
| 12 | 12.9 | 76.4 | 2.78 | 0.256 | 1.77 | 11.4 | 96.3 | 2.76 | 0.269 | 1.95 |
| 13 | 12.3 | 91.3 | 2.60 | 0.286 | 1.89 | 12.0 | 82.3 | 2.53 | 0.290 | 2.04 |
| 14 | 13.4 | 89.5 | 2.60 | 0.267 | 2.25 | 12.7 | 89.0 | 2.46 | 0.295 | 2.04 |
| 15 | 11.8 | 78.5 | 2.55 | 0.256 | 1.95 | 12.5 | 119.0 | 2.76 | 0.293 | 2.28 |
| 16 | 13.3 | 72.6 | 2.65 | 0.269 | 1.98 | 12.9 | 75.1 | 2.96 | 0.312 | 2.10 |
| 17 | 11.2 | 82.4 | 2.91 | 0.317 | 2.04 | 13.3 | 70.8 | 2.50 | 0.295 | 2.01 |
| 18 | 12.5 | 88.5 | 2.81 | 0.322 | 2.01 | 10.9 | 61.9 | 2.39 | 0.276 | 1.98 |
| 19 | 13.4 | 88.5 | 3.14 | 0.265 | 1.77 | 12.7 | 90.5 | 3.01 | 0.290 | 1.95 |
| 20 | 13.4 | 93.9 | 2.93 | 0.260 | 1.80 | 10.9 | 85.4 | 2.96 | 0.293 | 2.13 |
| 21 | 12.9 | 99.5 | 2.86 | 0.272 | 1.62 | 14.4 | 121.6 | 2.88 | 0.310 | 2.25 |
| 22 | 12.9 | 122.1 | 3.11 | 0.310 | 2.19 | 12.9 | 118.4 | 2.81 | 0.305 | 2.34 |
| 23 | 12.0 | 70.4 | 2.96 | 0.279 | 1.92 | 13.1 | 81.8 | 2.48 | 0.272 | 2.04 |

Table 54. (Continued)

| Treatment number | Experiment 7 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 8.4 | 52.2 | 1.87 | 0.205 | 1.50 | 10.7 | 78.6 | 2.31 | 0.242 | 1.44 |
| 2 | 11.3 | 85.7 | 2.23 | 0.226 | 1.44 | 10.3 | 69.5 | 2.14 | 0.208 | 1.38 |
| 3 | 9.5 | 57.4 | 1.92 | 0.207 | 1.41 | 12.0 | 74.9 | 2.08 | 0.212 | 1.35 |
| 4 | 11.7 | 81.7 | 2.26 | 0.239 | 1.62 | 9.7 | 73.4 | 2.31 | 0.256 | 1.47 |
| 5 | 12.0 | 78.7 | 2.47 | 0.231 | 1.23 | 11.7 | 81.3 | 2.40 | 0.238 | 1.17 |
| 6 | 8.7 | 69.3 | 2.38 | 0.233 | 1.38 | 12.4 | 82.5 | 2.54 | 0.244 | 1.62 |
| 7 | 10.3 | 79.3 | 2.51 | 0.248 | 1.20 | 10.9 | 74.1 | 2.40 | 0.272 | 1.26 |
| 8 | 10.9 | 81.9 | 2.28 | 0.235 | 1.50 | 9.9 | 79.3 | 2.44 | 0.272 | 1.50 |
| 9 | 10.9 | 80.3 | 2.36 | 0.226 | 1.38 | 10.5 | 75.4 | 2.21 | 0.240 | 1.35 |
| 10 | 8.7 | 56.7 | 2.14 | 0.226 | 1.59 | 11.7 | 72.9 | 2.25 | 0.222 | 1.74 |
| 11 | 11.8 | 83.1 | 2.57 | 0.239 | 1.41 | 10.5 | 73.2 | 2.31 | 0.258 | 1.20 |
| 12 | 10.7 | 77.0 | 2.25 | 0.233 | 1.44 | 10.1 | 73.4 | 2.29 | 0.205 | 1.71 |
| 13 | 11.7 | 90.9 | 2.29 | 0.251 | 1.41 | 10.1 | 71.3 | 2.35 | 0.267 | 1.41 |
| 14 | 9.3 | 69.0 | 2.44 | 0.249 | 1.23 | 10.7 | 66.9 | 2.61 | 0.281 | 1.29 |
| 15 | 10.9 | 78.0 | 2.33 | 0.238 | 1.32 | 12.6 | 76.5 | 2.24 | 0.227 | 1.41 |
| 16 | 10.3 | 67.9 | 2.33 | 0.251 | 1.65 | 10.7 | 66.8 | 2.26 | 0.210 | 1.53 |
| 17 | 9.7 | 64.4 | 2.03 | 0.225 | 1.35 | 10.7 | 63.8 | 1.98 | 0.221 | 1.38 |
| 18 | 9.3 | 52.5 | 1.81 | 0.233 | 1.50 | 12.0 | 67.2 | 1.82 | 0.216 | 1.65 |
| 19 | 11.7 | 70.8 | 2.35 | 0.203 | 1.26 | 8.9 | 54.2 | 2.21 | 0.182 | 1.26 |
| 20 | 10.9 | 70.4 | 2.29 | 0.210 | 1.80 | 9.5 | 65.4 | 2.56 | 0.206 | 1.56 |
| 21 | 9.5 | 65.6 | 2.37 | 0.264 | 1.02 | 10.9 | 72.4 | 2.45 | 0.267 | 0.90 |
| 22 | 12.0 | 81.7 | 2.35 | 0.229 | 1.71 | 10.3 | 76.2 | 2.50 | 0.272 | 1.47 |
| 23 | 10.9 | 55.5 | 1.92 | 0.171 | 1.29 | 10.3 | 55.8 | 2.11 | 0.208 | 1.20 |

Table 54. (Continued)

| Treatment number | Experiment 8 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.5 | 105.9 | 2.44 | 0.297 | 0.99 | 14.7 | 79.4 | 2.28 | 0.283 | 0.90 |
| 2 | 14.3 | 105.5 | 2.57 | 0.281 | 1.23 | 12.4 | 94.4 | 2.63 | 0.276 | 1.47 |
| 3 | 13.1 | 100.2 | 2.58 | 0.302 | 1.05 | 14.9 | 93.1 | 2.54 | 0.271 | 1.29 |
| 4 | 14.5 | 98.0 | 2.54 | 0.276 | 1.26 | 13.9 | 103.2 | 2.67 | 0.293 | 1.50 |
| 5 | 14.5 | 92.8 | 2.71 | 0.265 | 0.90 | 13.1 | 98.3 | 2.83 | 0.298 | 0.99 |
| 6 | 13.9 | 120.2 | 2.62 | 0.255 | 1.05 | 13.5 | 108.7 | 2.67 | 0.276 | 1.53 |
| 7 | 11.0 | 76.8 | 2.74 | 0.312 | 0.93 | 14.9 | 99.2 | 2.78 | 0.337 | 0.90 |
| 8 | 13.9 | 107.2 | 2.89 | 0.312 | 1.26 | 13.9 | 120.1 | 2.92 | 0.300 | 1.11 |
| 9 | 15.3 | 109.1 | 2.64 | 0.285 | 1.02 | 13.3 | 98.9 | 2.72 | 0.322 | 1.14 |
| 10 | 13.9 | 68.1 | 2.03 | 0.234 | 1.08 | 12.6 | 87.5 | 2.38 | 0.276 | 1.38 |
| 11 | 14.1 | 97.8 | 2.81 | 0.307 | 0.99 | 14.9 | 101.9 | 2.65 | 0.269 | 1.14 |
| 12 | 15.1 | 95.8 | 2.64 | 0.217 | 1.20 | 15.5 | 105.0 | 2.85 | 0.255 | 1.53 |
| 13 | 14.3 | 98.4 | 2.54 | 0.281 | 1.32 | 13.1 | 94.3 | 2.85 | 0.322 | 0.99 |
| 14 | 13.3 | 95.1 | 2.89 | 0.302 | 0.87 | 13.9 | 73.6 | 2.85 | 0.305 | 0.84 |
| 15 | 13.1 | 97.1 | 2.74 | 0.300 | 1.56 | 12.0 | 93.6 | 2.56 | 0.262 | 1.50 |
| 16 | 15.7 | 96.4 | 2.40 | 0.260 | 1.47 | 13.9 | 93.5 | 2.50 | 0.267 | 1.59 |
| 17 | 12.2 | 80.1 | 2.54 | 0.320 | 0.99 | 13.9 | 66.2 | 2.07 | 0.253 | 1.11 |
| 18 | 13.3 | 74.1 | 2.11 | 0.249 | 1.53 | 13.7 | 93.1 | 2.58 | 0.260 | 1.50 |
| 19 | 13.9 | 77.0 | 2.64 | 0.202 | 0.84 | 13.9 | 71.3 | 2.67 | 0.182 | 1.05 |
| 20 | 13.0 | 95.6 | 2.88 | 0.240 | 1.50 | 12.4 | 86.2 | 2.72 | 0.204 | 1.53 |
| 21 | 13.9 | 85.1 | 2.79 | 0.320 | 0.69 | 13.3 | 96.4 | 2.83 | 0.315 | 0.84 |
| 22 | 16.0 | 111.7 | 2.74 | 0.295 | 1.32 | 13.7 | 100.2 | 2.81 | 0.288 | 1.23 |
| 23 | 11.6 | 78.2 | 2.54 | 0.260 | 0.93 | 14.9 | 86.2 | 2.61 | 0.245 | 1.05 |

Table 54. (Continued)

| Treatment number | Experiment 9 | | | | | | | | | |
|---------------------|--------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 16.5 | 81.5 | 2.19 | 0.231 | 1.62 | 17.8 | 98.3 | 2.08 | 0.241 | 1.35 |
| 2 | 16.9 | 77.3 | 2.26 | 0.220 | 1.71 | 14.7 | 75.2 | 2.38 | 0.237 | 1.68 |
| 3 | 16.5 | 83.1 | 2.55 | 0.259 | 1.47 | 16.5 | 86.6 | 2.03 | 0.250 | 1.53 |
| 4 | 17.6 | 84.4 | 2.30 | 0.241 | 1.74 | 17.8 | 87.5 | 2.15 | 0.241 | 1.59 |
| 5 | 14.9 | 94.5 | 2.45 | 0.241 | 1.65 | 17.1 | 91.6 | 2.50 | 0.268 | 1.26 |
| 6 | 18.0 | 90.4 | 2.35 | 0.261 | 1.89 | 16.5 | 88.8 | 2.48 | 0.246 | 1.56 |
| 7 | 15.8 | 78.9 | 2.38 | 0.262 | 1.65 | 17.4 | 86.4 | 2.58 | 0.287 | 1.62 |
| 8 | 17.8 | 87.8 | 2.38 | 0.244 | 1.47 | 17.4 | 90.1 | 2.43 | 0.268 | 1.50 |
| 9 | 19.1 | 87.8 | 2.25 | 0.241 | 1.74 | 17.1 | 81.9 | 2.43 | 0.237 | 1.44 |
| 10 | 16.7 | 80.1 | 2.03 | 0.220 | 1.53 | 15.3 | 86.8 | 2.12 | 0.235 | 1.65 |
| 11 | 16.7 | 82.4 | 2.48 | 0.273 | 1.59 | 16.9 | 93.8 | 2.57 | 0.276 | 1.77 |
| 12 | 16.7 | 83.1 | 2.45 | 0.236 | 1.59 | 17.4 | 87.3 | 2.40 | 0.234 | 1.44 |
| 13 | 17.6 | 80.7 | 2.21 | 0.249 | 1.53 | 16.7 | 92.9 | 2.40 | 0.244 | 1.59 |
| 14 | 16.2 | 89.0 | 2.38 | 0.255 | 1.35 | 17.1 | 90.6 | 2.47 | 0.257 | 1.77 |
| 15 | 17.6 | 76.9 | 2.40 | 0.255 | 1.80 | 16.0 | 88.8 | 2.55 | 0.238 | 1.59 |
| 16 | 16.5 | 80.5 | 2.16 | 0.231 | 1.65 | 16.5 | 92.1 | 2.36 | 0.240 | 1.50 |
| 17 | 18.2 | 91.4 | 2.11 | 0.214 | 1.35 | 15.6 | 100.4 | 2.22 | 0.267 | 1.89 |
| 18 | 14.5 | 74.2 | 2.07 | 0.225 | 1.65 | 16.0 | 79.1 | 2.17 | 0.225 | 1.65 |
| 19 | 16.7 | 84.4 | 2.53 | 0.259 | 1.50 | 17.6 | 81.2 | 2.32 | 0.222 | 1.59 |
| 20 | 17.1 | 91.8 | 2.20 | 0.231 | 1.83 | 14.5 | 76.7 | 2.40 | 0.251 | 1.86 |
| 21 | 19.1 | 76.7 | 2.30 | 0.246 | 1.56 | 15.8 | 90.5 | 2.42 | 0.239 | 1.50 |
| 22 | 17.1 | 87.8 | 2.50 | 0.266 | 1.62 | 17.8 | 99.0 | 2.44 | 0.276 | 1.86 |
| 23 | 16.5 | 91.9 | 2.38 | 0.248 | 1.77 | 16.9 | 84.4 | 2.47 | 0.239 | 1.62 |

Table 54. (Continued)

| Treatment number | Experiment 10 | | | | | | | | | |
|---------------------|---------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.0 | 123.6 | 2.89 | 0.332 | 2.37 | 14.0 | 111.8 | 2.77 | 0.293 | 1.92 |
| 2 | 14.6 | 129.1 | 2.92 | 0.335 | 2.52 | 13.6 | 118.9 | 2.82 | 0.318 | 2.10 |
| 3 | 14.9 | 124.3 | 2.71 | 0.315 | 2.28 | 14.9 | 124.8 | 2.77 | 0.320 | 2.01 |
| 4 | 14.2 | 109.9 | 2.92 | 0.356 | 2.28 | 13.6 | 115.5 | 2.71 | 0.310 | 2.25 |
| 5 | 14.6 | 129.5 | 3.08 | 0.322 | 2.70 | 14.9 | 125.3 | 2.98 | 0.310 | 2.10 |
| 6 | 16.8 | 129.3 | 3.01 | 0.330 | 2.97 | 15.1 | 127.5 | 2.87 | 0.303 | 2.25 |
| 7 | 14.7 | 128.4 | 3.06 | 0.375 | 2.28 | 14.4 | 133.7 | 2.77 | 0.330 | 2.16 |
| 8 | 13.8 | 123.2 | 2.92 | 0.345 | 2.64 | 13.4 | 123.1 | 3.03 | 0.333 | 2.10 |
| 9 | 14.2 | 123.5 | 3.07 | 0.327 | 2.28 | 14.9 | 124.3 | 2.91 | 0.324 | 1.98 |
| 10 | 15.3 | 116.2 | 2.77 | 0.302 | 2.34 | 14.0 | 114.9 | 2.75 | 0.312 | 2.22 |
| 11 | 17.7 | 137.4 | 2.89 | 0.317 | 2.64 | 13.8 | 124.6 | 3.00 | 0.320 | 2.04 |
| 12 | 13.8 | 125.6 | 3.01 | 0.324 | 2.22 | 13.6 | 116.9 | 3.12 | 0.322 | 2.64 |
| 13 | 15.3 | 119.0 | 2.89 | 0.338 | 2.22 | 13.4 | 118.0 | 2.90 | 0.328 | 1.95 |
| 14 | 14.0 | 120.9 | 2.93 | 0.310 | 2.40 | 14.9 | 126.6 | 2.87 | 0.320 | 2.16 |
| 15 | 14.7 | 125.8 | 2.87 | 0.325 | 2.43 | 15.3 | 124.3 | 2.77 | 0.305 | 2.04 |
| 16 | 13.4 | 110.9 | 2.85 | 0.298 | 2.34 | 11.8 | 89.9 | 2.85 | 0.286 | 2.22 |
| 17 | 14.9 | 124.3 | 2.71 | 0.305 | 2.40 | 14.2 | 116.8 | 2.65 | 0.312 | 2.22 |
| 18 | 14.0 | 125.8 | 2.79 | 0.325 | 2.70 | 11.9 | 99.5 | 2.72 | 0.305 | 2.25 |
| 19 | 13.1 | 119.0 | 2.93 | 0.310 | 2.22 | 15.3 | 125.1 | 3.06 | 0.281 | 1.98 |
| 20 | 14.7 | 128.8 | 3.05 | 0.324 | 2.40 | 14.0 | 124.7 | 3.07 | 0.314 | 2.25 |
| 21 | 15.5 | 133.5 | 3.09 | 0.346 | 2.34 | 13.8 | 123.9 | 3.01 | 0.343 | 2.16 |
| 22 | 15.9 | 123.8 | 3.00 | 0.338 | 2.61 | 15.1 | 135.7 | 3.13 | 0.368 | 2.25 |
| 23 | 14.2 | 111.2 | 2.71 | 0.291 | 2.16 | 11.9 | 86.6 | 2.83 | 0.286 | 2.22 |

Table 54. (Continued)

| Treatment number | Experiment 11 | | | | | | | | | |
|---------------------|---------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 14.7 | 94.4 | 2.41 | 0.262 | 1.86 | 14.9 | 94.5 | 2.49 | 0.290 | 2.04 |
| 2 | 14.1 | 77.6 | 2.18 | 0.242 | 1.77 | 13.9 | 103.1 | 2.67 | 0.299 | 1.86 |
| 3 | 14.9 | 93.9 | 2.63 | 0.292 | 1.95 | 13.9 | 78.6 | 2.35 | 0.251 | 1.59 |
| 4 | 13.0 | 97.3 | 2.72 | 0.312 | 1.77 | 13.9 | 80.4 | 2.69 | 0.299 | 1.86 |
| 5 | 14.3 | 91.3 | 2.85 | 0.309 | 1.71 | 14.5 | 104.6 | 2.72 | 0.297 | 1.53 |
| 6 | 13.7 | 96.3 | 2.77 | 0.290 | 1.95 | 14.3 | 91.7 | 2.67 | 0.297 | 1.92 |
| 7 | 14.1 | 84.8 | 2.67 | 0.309 | 1.83 | 14.5 | 102.8 | 2.73 | 0.335 | 1.74 |
| 8 | 14.7 | 93.9 | 2.72 | 0.309 | 1.92 | 14.3 | 93.8 | 2.51 | 0.292 | 1.71 |
| 9 | 14.9 | 89.4 | 2.69 | 0.307 | 1.86 | 15.1 | 102.0 | 2.62 | 0.302 | 1.86 |
| 10 | 14.1 | 80.7 | 2.30 | 0.261 | 2.07 | 14.7 | 70.6 | 2.15 | 0.255 | 2.10 |
| 11 | 14.7 | 98.7 | 2.88 | 0.319 | 1.89 | 14.9 | 106.5 | 2.74 | 0.327 | 1.86 |
| 12 | 14.5 | 91.5 | 2.79 | 0.276 | 1.86 | 15.2 | 101.8 | 2.88 | 0.314 | 2.01 |
| 13 | 14.1 | 87.4 | 2.63 | 0.307 | 1.80 | 13.4 | 82.8 | 2.77 | 0.324 | 1.86 |
| 14 | 14.3 | 95.1 | 3.07 | 0.319 | 1.47 | 14.1 | 97.9 | 2.85 | 0.304 | 1.65 |
| 15 | 14.3 | 100.4 | 3.04 | 0.319 | 1.89 | 14.3 | 97.3 | 2.81 | 0.299 | 1.62 |
| 16 | 14.1 | 96.6 | 2.61 | 0.285 | 2.16 | 13.7 | 87.6 | 2.43 | 0.290 | 2.04 |
| 17 | 13.7 | 84.9 | 2.18 | 0.257 | 1.68 | 14.1 | 85.8 | 2.37 | 0.287 | 1.89 |
| 18 | 13.7 | 66.7 | 2.04 | 0.242 | 2.10 | 14.5 | 54.8 | 1.76 | 0.220 | 1.74 |
| 19 | 15.4 | 95.1 | 2.67 | 0.290 | 1.29 | 14.3 | 97.3 | 2.95 | 0.290 | 1.62 |
| 20 | 14.7 | 100.0 | 2.88 | 0.307 | 2.19 | 15.1 | 94.8 | 2.74 | 0.262 | 1.86 |
| 21 | 15.1 | 96.2 | 2.83 | 0.332 | 1.53 | 13.9 | 99.4 | 3.02 | 0.345 | 1.80 |
| 22 | 14.5 | 85.1 | 2.61 | 0.287 | 1.62 | 14.1 | 100.3 | 2.77 | 0.393 | 2.01 |
| 23 | 13.9 | 81.9 | 2.31 | 0.283 | 2.04 | 13.0 | 74.3 | 2.19 | 0.239 | 1.65 |

Table 54. (Continued)

| Treatment number | Experiment 12 | | | | | | | | | |
|---------------------|---------------|-------|------|-------|------|-------------|-------|------|-------|------|
| | Replicate 1 | | | | | Replicate 2 | | | | |
| | Stand | Yield | %N | %P | %K | Stand | Yield | %N | %P | %K |
| 1 | 11.4 | 52.2 | 1.96 | 0.257 | 1.62 | 12.1 | 57.2 | 2.52 | 0.271 | 1.29 |
| 2 | 9.7 | 43.4 | 2.14 | 0.332 | 1.62 | 13.4 | 76.4 | 2.79 | 0.271 | 1.56 |
| 3 | 11.9 | 63.6 | 2.50 | 0.297 | 1.38 | 12.5 | 66.9 | 2.33 | 0.267 | 1.47 |
| 4 | 13.3 | 63.3 | 2.19 | 0.271 | 1.74 | 12.1 | 69.5 | 2.61 | 0.310 | 1.35 |
| 5 | 12.7 | 88.5 | 3.26 | 0.300 | 1.35 | 11.8 | 78.5 | 3.05 | 0.278 | 1.20 |
| 6 | 12.5 | 78.3 | 3.03 | 0.290 | 1.50 | 12.7 | 84.4 | 3.13 | 0.297 | 1.32 |
| 7 | 12.9 | 74.7 | 2.68 | 0.285 | 1.50 | 12.5 | 74.7 | 2.97 | 0.307 | 1.02 |
| 8 | 12.9 | 80.0 | 2.97 | 0.300 | 1.44 | 11.8 | 77.8 | 3.13 | 0.320 | 1.26 |
| 9 | 11.2 | 69.1 | 2.79 | 0.278 | 1.26 | 12.1 | 75.3 | 2.81 | 0.273 | 1.47 |
| 10 | 11.4 | 48.3 | 2.19 | 0.320 | 1.47 | 11.8 | 59.4 | 2.50 | 0.322 | 1.65 |
| 11 | 13.1 | 82.8 | 2.86 | 0.283 | 1.44 | 12.3 | 75.9 | 3.24 | 0.325 | 1.14 |
| 12 | 12.7 | 70.1 | 3.06 | 0.249 | 1.62 | 12.7 | 69.5 | 3.05 | 0.266 | 1.26 |
| 13 | 13.8 | 86.5 | 2.76 | 0.285 | 1.62 | 12.9 | 76.0 | 2.76 | 0.294 | 1.41 |
| 14 | 11.2 | 58.0 | 2.57 | 0.290 | 1.29 | 11.8 | 78.0 | 3.07 | 0.287 | 1.26 |
| 15 | 11.9 | 71.2 | 2.63 | 0.288 | 1.71 | 13.6 | 83.3 | 2.83 | 0.282 | 1.38 |
| 16 | 11.6 | 45.0 | 2.03 | 0.269 | 1.83 | 13.3 | 58.1 | 2.33 | 0.241 | 1.53 |
| 17 | 11.4 | 42.0 | 2.05 | 0.367 | 1.65 | 11.6 | 43.4 | 2.19 | 0.348 | 1.50 |
| 18 | 9.5 | 36.4 | 2.01 | 0.386 | 1.77 | 11.4 | 55.1 | 2.19 | 0.294 | 1.56 |
| 19 | 10.1 | 57.5 | 2.97 | 0.269 | 1.50 | 11.6 | 64.7 | 3.36 | 0.280 | 1.11 |
| 20 | 12.1 | 85.2 | 3.46 | 0.278 | 1.50 | 11.9 | 85.9 | 3.28 | 0.299 | 1.50 |
| 21 | 13.8 | 95.5 | 3.16 | 0.320 | 1.14 | 11.6 | 75.4 | 3.24 | 0.332 | 1.05 |
| 22 | 14.6 | 97.8 | 2.79 | 0.305 | 1.41 | 14.9 | 105.7 | 3.18 | 0.330 | 1.32 |
| 23 | 11.4 | 46.5 | 2.45 | 0.262 | 1.56 | 11.9 | 57.1 | 2.60 | 0.248 | 1.38 |

Table 55. Coded X matrix of the experimental design for the six 1959 experiments

| X_0 | N | P | K | N^2 | P^2 | K^2 | NP | NK | PK |
|-------|----|----|----|-------|-------|-------|----|----|----|
| 1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 |
| 1 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 |
| 1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 1 |
| 1 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 |
| 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | 1 | -1 |
| 1 | 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | -2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | -2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 1 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | -2 | 0 | 0 | 4 | 0 | 0 | 0 |
| 1 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 0 |
| 1 | -2 | 2 | 2 | 4 | 4 | 4 | -4 | -4 | 4 |
| 1 | 2 | -2 | 2 | 4 | 4 | 4 | -4 | 4 | -4 |
| 1 | 2 | 2 | -2 | 4 | 4 | 4 | 4 | -4 | -4 |
| 1 | -2 | -2 | -2 | 4 | 4 | 4 | 4 | 4 | 4 |

Table 56. Elements of the inverse matrix for the 1959 experimental design

| Elements | | | | |
|-----------|-----------|----------|----------|-----------|
| c_{00} | c_{01} | c_{02} | c_{03} | c_{04} |
| 0.151220 | 0.000000 | 0.000000 | 0.000000 | -0.019512 |
| 0.000000 | 0.056250 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.056250 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.056250 | 0.000000 |
| -0.019512 | 0.000000 | 0.000000 | 0.000000 | 0.024695 |
| -0.019512 | 0.000000 | 0.000000 | 0.000000 | -0.006555 |
| -0.019512 | 0.000000 | 0.000000 | 0.000000 | -0.006555 |
| 0.000000 | 0.000000 | 0.000000 | 0.025000 | 0.000000 |
| 0.000000 | 0.000000 | 0.025000 | 0.000000 | 0.000000 |
| 0.000000 | 0.025000 | 0.000000 | 0.000000 | 0.000000 |
| c_{05} | c_{06} | c_{07} | c_{08} | c_{09} |
| -0.019512 | -0.019512 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.025000 |
| 0.000000 | 0.000000 | 0.000000 | 0.025000 | 0.000000 |
| 0.000000 | 0.000000 | 0.025000 | 0.000000 | 0.000000 |
| -0.006555 | -0.006555 | 0.000000 | 0.000000 | 0.000000 |
| 0.024695 | -0.006555 | 0.000000 | 0.000000 | 0.000000 |
| -0.006555 | -0.024695 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.025000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.025000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.025000 |

Table 57. Coded X matrix of the experimental design for the twelve 1960 experiments

| X_0 | N | P | K | N^2 | P^2 | K^2 | NP | NK | PK |
|-------|----|----|----|-------|-------|-------|----|----|----|
| 1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 |
| 1 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 |
| 1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 1 |
| 1 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 |
| 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | 1 | -1 |
| 1 | 1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | -2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | -2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 1 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | -2 | 0 | 0 | 4 | 0 | 0 | 0 |
| 1 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 0 |
| 1 | -2 | -2 | 2 | 4 | 4 | 4 | 4 | -4 | -4 |
| 1 | -2 | 2 | -2 | 4 | 4 | 4 | -4 | 4 | -4 |
| 1 | -2 | 2 | 2 | 4 | 4 | 4 | -4 | -4 | 4 |
| 1 | 2 | -2 | -2 | 4 | 4 | 4 | -4 | -4 | 4 |
| 1 | 2 | -2 | 2 | 4 | 4 | 4 | -4 | 4 | -4 |
| 1 | 2 | 2 | -2 | 4 | 4 | 4 | 4 | -4 | -4 |
| 1 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 |
| 1 | -2 | -2 | -2 | 4 | 4 | 4 | 4 | 4 | 4 |

Table 58. Elements of the inverse matrix for the 1960 experimental design

| Elements | | | | |
|-----------|-----------|----------|----------|-----------|
| C_{00} | C_{01} | C_{02} | C_{03} | C_{04} |
| 0.137157 | 0.000000 | 0.000000 | 0.000000 | -0.014962 |
| 0.000000 | 0.020833 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.020833 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.020833 | 0.000000 |
| -0.014962 | 0.000000 | 0.000000 | 0.000000 | 0.023223 |
| -0.014962 | 0.000000 | 0.000000 | 0.000000 | -0.008027 |
| -0.014962 | 0.000000 | 0.000000 | 0.000000 | -0.008027 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| C_{05} | C_{06} | C_{07} | C_{08} | C_{09} |
| -0.014962 | -0.014962 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| -0.008027 | -0.008027 | 0.000000 | 0.000000 | 0.000000 |
| 0.023223 | -0.008027 | 0.000000 | 0.000000 | 0.000000 |
| -0.008027 | 0.023223 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.007353 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.007353 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.007353 |